ACCURACY OF SURFACE MODELS ACQUIRED FROM DIFFERENT SOURCES — IMPORTANT INFORMATION FOR GEOMORPHOLOGICAL RESEARCH

*KAREL JEDLIČKA**

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The article deals with definitions of surface models, their representations and accuracy. A surface is associated with Earth in geo-related sciences. First various existing types of Earth's surface models are described which can be stored in computer in different representations. The description of three different data acquisition methods (topographical mapping, stereophotogrammetry and laser scanning) which can produce surface data follows. Each method has a typical primary digital representation, which is mentioned. Also the accuracy of data models differs (depending on data acquisition method). Finally, described methods are compared and the vision of the surface models acquisition and storage is briefly outlined.

Key words: digital terrain model, digital elevation model, digital surface model, topographic mapping, stereophotogrammetry, LIDAR, laser scan, accuracy, geomorphology

MOTIVATION

The aim of this article is to show to geomorphologists, that it is useful to know the data acquisition method, because precision of resultant data varies depending on selected method of data acquisition and character of the area of interest. Problematic areas are generally steep slopes and/or areas covered by vegetation (typical condition in geomorphological research). Even if the geomorphologist usually cannot choose the method of acquisition, it is still useful to know the method used in the area of interest and to know where the aggravation of precision can be expected[1].

TYPES OF EARTH'S SURFACE MODELS

It is possible to find different definitions of digital models, which represent Earth's surface, but following definitions are used in this article:

A **digital terrain model** (DTM) is a digital representation of terrain relief of Earth surface (georelief) in computer memory, composed of (sample) data and algorithm which can interpolate heights of intermediary points (ŠÍMA 2003).

A **digital elevation model** (DEM) is a digital terrain model which deals with elevations above sea level (ŠÍMA 2003).

A **digital surface model** (DSM) is usually constructed using automatic extraction algorithms (i.e. image correlation in stereo photogrammetry or first-return LIDAR pulse[2]). DSM represents top faces of all objects on the terrain (both vegetation and manmade features) or terrain itself in open areas. Taken and adapted from ŠÍMA (2003). See the difference between DTM and DSM at **Figure 1**.

There exist (later mentioned) another term: **digital landscape model** (DLM), which sounds similar, but it has a different meaning. Eurogeographics 2009 defines DLM as an object oriented topographic database with the data structure facilitated to spatial analysis and linkage of geographic objects to external data (represented as vector geometric primitives). It contains both elevation and planimetric data.

Consequent on mentioned definitions, we can understand DEM as a special type of

[1]The article ends at the primary digital representation of the data, it is not focused on interpolation techniques, their algorithms and accuracies. This is described e.g. in BONK 2003

[2]LIDAR – LIght Detection And Ranging. See more about LIDAR bellow

*Západočeská univerzita v Plzni, Univerzitní 22, Plzeň, 306, 14 Česká republika
e-mail: smrcek@kma.zcu.cz

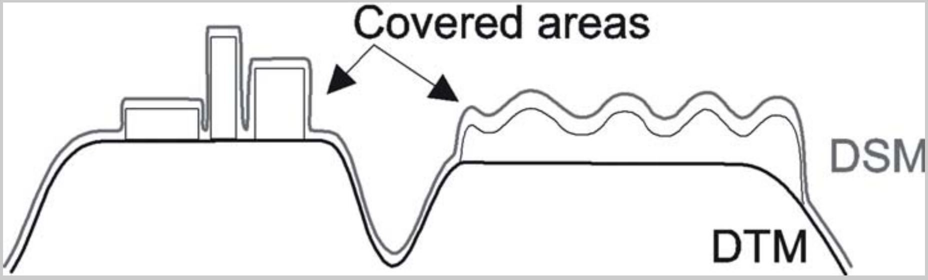

Fig.1 Difference between DTM (or DEM) and DSM

DTM, which deals with elevations a raw data product of automatic surface extraction (**Fig. 1**).

TYPES OF SURFACE REPRESENTATIONS

We should distinguish between term model and representation. While model is closely tied to the phenomenon which models, no matter how it is represented, representation just says how to represent certain type of data (in a map, in a computer …), no matter what the data means. Because models of surfaces deal with spatial data, they use spatial representations. Then we can say that DTM, DEM, DSM or another surface can be represented by vector, raster or other representation.

Vector representation

In vector, two typical ways of representation can be used, depending on the structure of input data. First is general vector based geometric primitives: points, lines and polygons:

Point – one set S_p of coordinates, usually $[X_p, Y_p, Z_p]$.

Line – ordered list of coordinate sets $S_1, .. S_n$, where S_n can, but doesn't have to, be equal to S_1.[3]

Polygon – ordered list of coordinate sets $S_1, .. , S_{n-1}, S_n$, where S_n has to be equal to S_1.[4]

Typical way of using such a structure to store surface data is focused on storing contour lines and spot heights, which can be complement with talwegs, ridge lines and other terrain edges. These descriptive data are stored as attributes. Detailed specification and categorization of vector features whose describe relief is e.g. in RAPANT 1998.

The second vector representation is Triangulated Irregular Network (TIN). It is a special type of vector representation, which has been primarily developed for surface modelling based primarily on Delaunay triangulation

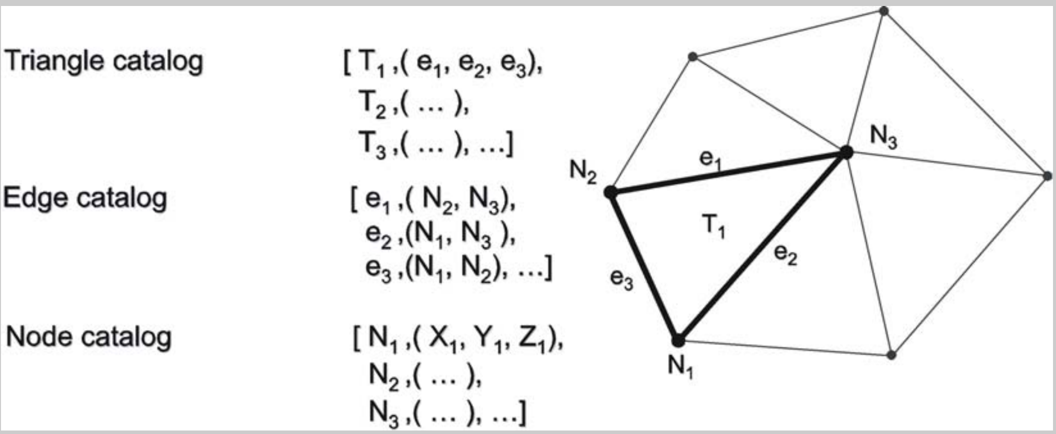

Fig. 2 Structure of TIN

[3]When Sn = S1, then the line is closed. Contour line is an example of closed line

[4]Storing to different types of lists (or tables or files) defines whether it is a closed line or polygon. Closed ring stored in Line list is closed line. Ring in polygon list of course means a polygon

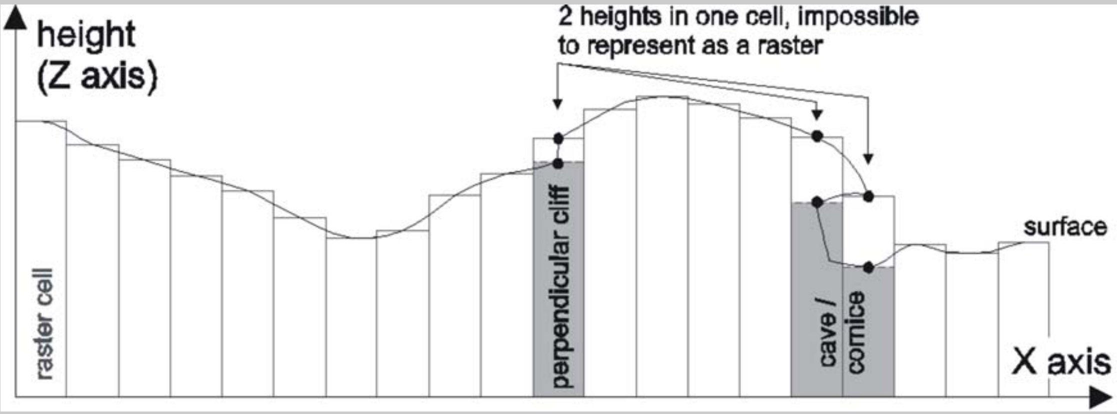

Fig. 3 Example of a 2.5 dimension character of a raster representation of a surface (depicted on an example of a grid)

combined with a concept of forced edges (described e.g. in GOODCHILD and KEMP eds. 1990 or TUČEK 1998).

TIN usually sample surface specific points, such as peaks, ridges and breaks in slope (MOORE et al. 1991). The common TIN representation stores data in three related catalogs. Node catalog, edge catalog and triangle catalog, see **Figure 2**.

Note: Although a vector representation potentially can model full three dimensions, for representation of surfaces a 2,5 D representation is used in geographic information systems (GIS). It means that the value of surface (e.g. elevation – *Z*) is defined as a function of positional coordinates X, Y (1):

$$Z = F(X_i, Y_j); \quad i = 1 \,..\, n, j = 1 \,..\, m. \qquad (1).$$

RASTER REPRESENTATION

Raster representation of surface usually stores data into two dimensional field of $[X_i, Y_j]$ coordinates (where $i = 1 \,..\, n, j = 1 \,..\, m$), for which exactly one surface value (usually coded *Z*) is assigned (1). Therefore surfaces with overhangs – such as digital landscape model (DLM) with bridges, surface with caves, cornices or cliffs – cannot be correctly represented (**Fig. 3**):

Raster representation stores data in regular **grids** or **lattices**. While grid is composed of cells, lattice is composed of discrete points. It means that the grid cell value is valid for whole cell which is defined as an area. E.g. orthophoto or satellite imagery can be represented by a grid. On the other hand, lattice points represent the value just in their current *X*,*Y* position[5]. The value continuously changes among lattice points. Surface models are a typical example of lattice representation. See difference between grid and lattice in **Figure 4.**

Even if there are two types of raster representation (grid or lattice), storage of them is identical (1). Just the user distinguishes the difference depending on stored phenomenon character.

OTHER REPRESENTATIONS

Surface can be also described and represented by various types of mathematical relations, e.g. spline surfaces (more in JEŽEK 2000), but they are not discussed in this article, because just first three mentioned representations (geometric primitives, TIN or raster) are used in geographical software nowadays.

Note: **Data format** is a representation implemented in particular software or defined by a standard (such as International standard organization – ISO or Open Geospatial Consortium – OGC). Many data formats exist, but they are not discussed in this article.

SURFACE DATA ACQUISITION METHODS AND TYPICAL DEFECTS OF RESULTANT DTM (/DEM)

In this section are described methods of data acquisition (mapping methods) and their accuracy. The accuracy is in literature sometimes described just generally – for non-prob-

[5]There could appear a problem during creating TIN from lattice, because the area among 4 lattice points does not have to be flat there are two possibilities to divide it into triangles (see **Fig. 4** upper right)

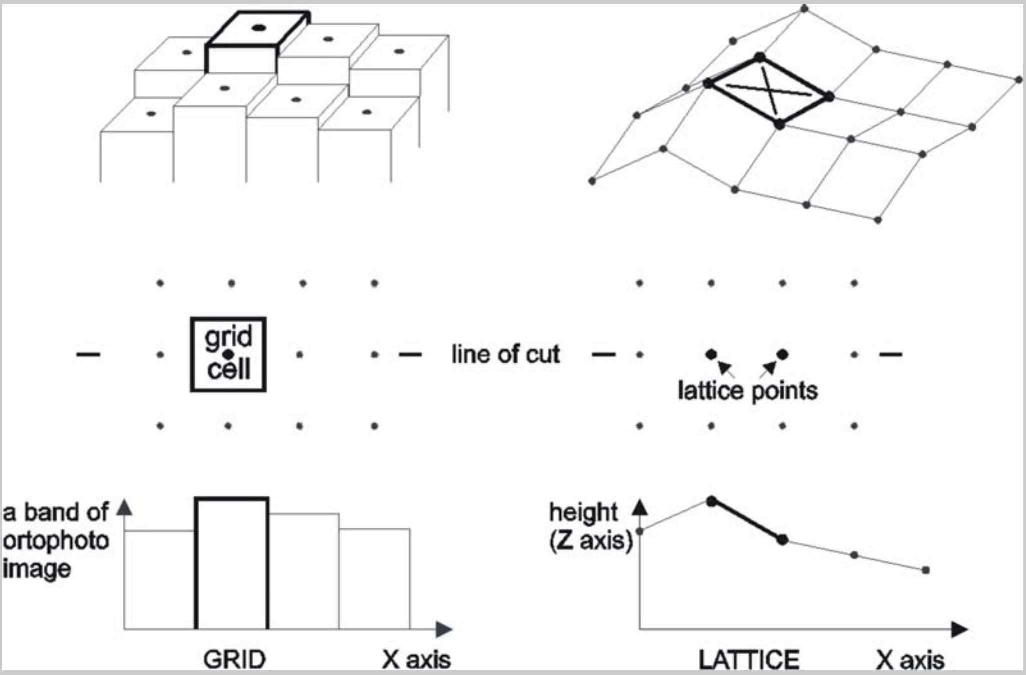

Fig.4 Difference between grid and lattice

lematic areas. This chapter focuses on description of types of areas, where it is possible to expect aggravation of accuracy. These area types differ depending on a mapping method.

TOPOGRAPHIC MAPPING

Classical geodetic and topographic mapping methods, such as polygonal traverse, trigonometric height measurement and tachymetry are used in combination with various types of leveling. See more e.g. in ÚSGK 1957.

Mass points measured by these methods can have precision better than 0,1 m both in position and height, when modern measuring instruments are used[6]. The precision of the mass points is one of key factors, which influents the resultant accuracy of DTM.

These points cover area of interest irregularly and their distribution is affected by surveyor's skills, experiences and geomorphologic knowledge. They has to be measured onto all lines of slope changes, because the only possibility how to afterwards derive height information among measured points, is to interpolate it among known points[7]. The methodology of terrain mapping of particular type of map is usually described in a standard. Such a standard is afterwards an excellent source to understand accuracy of DTM source data.

Vegetation cover of Earth surface and slope are other important factors what really strongly affect the resultant accuracy. The accuracy deteriorates when the slope is coming steeper or the land cover is coming denser.

A description of quality characteristic of DTM (controlled) follows. To do such a type of quality control of DTM, much more detailed DTM is necessary, which is considered as absolutely accurate for these purposes – accurate DTM (see more in ŠÍMA and EGRMAJEROVÁ 2004). A deviation is a difference between height value of controlled DTM and accurate DTM. There usually exist maximum allowed deviations for uncovered/covered areas in range of slopes described in methodologies of mapping particular set of maps. E.g., maximum allowed deviations of contour lines in topographic maps in scale 1:10 000 are described in BOGUSZAK and ŠLITR 1962 and KUČERA 1961. These limits are based on a modification of empirically discovered Koppe equation[8] – a Raabe equation (2), which

[6]The precision is usually worse in older topographic mappings. E.g. maximum allowed deviations 2 m in position and 0.4 m in elevation of polygonal traverse points are mentioned for numeric tachymetry (in ŠÍMA and EGRMAJEROVÁ 2004)

[7]Interpolation what respects nature of relief should be used. E.g. morphological interpolation (BOGUSZAK and ŠLITR 1962) or quintic interpolation (ESRI 2001) are better than linear

[8] Koppe empirically discovered that medium elevation error grows in correlation with slope and that this error can be described by an equation

better suit to statistical characteristic of mapping methods (see more about deriving these equations in BOGUSZAK and ŠLITR 1962):

$$d_{\max} = 2 \cdot \sigma = 2 \cdot \sqrt{a^2 + (b \cdot tg\alpha)^2} \qquad (2),$$

where d_{max} means maximum of allowed deviation of elevation of a contour line. α is a slope angle, *a* and *b* are constant parameters, that were empirically derived from large amount of control measurements and its statistical evaluation. Coefficient *a* represents error on a flat surface. Coefficient b represents relation of slope effect to the resultant d_{max}. σ is a mean error.

KUČERA 1961 determines coefficients for cartographic originals of maps in scale 1:10 000 (a = 0.69, b = 4.2 for uncovered terrain and a = 0.95, b = 8.4 for covered terrain).

BOGUSZAK and ŠLITR 1962 use a modification of Raabe equation, where parameter *s* (slope in %) is used instead of tg α (see 3). These coefficients also are not valid for cartographic originals, but for printed maps. Therefore coefficients *a* and *b* of the equations are different (a = 1.76, b = 0.084 for uncovered terrain and a = 2.4, b = 0.18 for covered terrain). They produce just slightly different (bigger) allowed deviations than coefficients from KUČERA (1961). **Table 1** shows comparison of maximum allowed elevation deviations of contour lines of topographic maps in scale 1:10 000 (topographically measured), accor-ding to KUČERA 1961 and BOGUSZAK and ŠLITR 1962.

$$d_{\max} = \sqrt{a^2 + (b \cdot s)^2} \qquad (3).$$

Above mentioned deviations are the maximal allowed deviations (d_{max}). It means, that mean error (σ) is 1/2 of d_{max} and also that all measured deviations have to be smaller than d_{max}. 2/3 of values have to be smaller than σ. Everything what is bigger than d_{max} is an error. Less than 5 % of measured values have to be errors, otherwise the controlled data is not accepted as a source of DTM.

The quality of elevation model is also directly proportional to importance of area of interest for human exploration. Topographic maps are created mainly for orientation around settlements, roads, railroads, etc. Contour lines are simplified and smoothed (generalized) in deep forests[9], high mountains, etc., because it would be too complex and expensive to map the DTM there in the same accuracy.

The last important factor is that topographical mapping of elevations was (and still often is) primarily used for creation of maps. Methods of cartographic generalization are applied to important planimetric features, which are simplified, exaggerated, moved, etc. Contour lines are after adjusted to spatially match to these features. Contours are also erased under rivers, roads and settlement areas, when the map is printed. It creates areas of poor elevation information.

As arise from this section, contour lines, and elevation spots complement with talwegs, ridge lines and other terrain edges stored as geometric primitives is a common primary representation of DTM created by topographical mapping.

STEREOPHOTOGRAMMETRY

Stereophotogrammetry is a method based on stereo perception. Typical outputs are ortophotomaps and DTM. The stereo perception grows, when the area of interest is percept from 2 slightly different camera positions. Stereo measurement, which is based on this principle, is used for surface reconstruction and storage in digital form (see details e.g. in ERDAS 2001). Terrestrial and aerial stereophotogrammetry exist, but the aerial is used for creating DTM.

Accuracy of DTM created by stereo measurement depends on many parameters[10]. Following description of the accuracy is adapted from ŠÍMA and EGRMAJEROVÁ 2004.

First parameter is a mean error of internal accuracy of analog stereophotogrammetric elevation measurement (σ) what mostly depends on a flight height. σ is described by relation (4) which has been derived from measurement of accuracy of many stereophotogrammetric elevation measurements.

$$\sigma = 0.015\% \cdot h \qquad (4),$$

where *h* is the flight height.

Usual mean flight height over the terrain for creating ortophotomaps with pixel size 0.5 m is approximately 3500 m or less. It can be calculated from an equation, which has been mentioned e.g. in PAVELKA 2003. Flight height

[9] E.g. for Base (topographical) map 1:10 000 of Czech Republic, deep forest means an area larger than 25 hectares (ŠÍMA and EGRMAJEROVÁ 2004)

[10] Parameters of frame camera, accuracy of camera position, aerial triangulation, etc. And last but not least, operator's experience. See a description of the stereophotogrammetrical process of DTM creation e.g. in ERDAS 2001

Slope in %	Slope in °	d_{max} in meters			
		Uncovered terrain		Covered terrain	
		Kučera	B&Š	Kučera	B&Š
0-5	0	1.4	1.8	2.0	2.6
5-10	2.25	1.5	2.0	2.3	3.0
10-20	4.5	1.9	2.4	3.3	4.3
20-30	9	2.4	3.1	4.5	5.9
30-40	13.5	3.1	3.8	5.8	7.6
40-50	18	3.7	4.5	7.2	9.3
50-60	22.5	4.5	5.3	8.8	11.0
More than 60	More than 22.5	$d_{\max} = 2 \cdot \sqrt{0.69^2 + (4.2 \cdot tg\, a)^2}$	$d_{\max} = \sqrt{1.76^2 + (0.084 \cdot s)^2}$	$d_{\max} = 2 \cdot \sqrt{0.95^2 + (8.4 \cdot tg\, a)^2}$	$d_{\max} = \sqrt{2.4^2 + (0.18 \cdot s)^2}$

Tab. 1 Maximum allowed elevation deviations of contour lines of topographic maps in scale 1:10 000 (topographically measured)

used for stereophotogrammetric creating of original Topographic map in scale 1:10 000 was around 2730 m (ŠÍMA and EGRMAJEROVÁ 2004). Thus, σ = 0.41 m in this example.

Next two parameters which influence resultant accuracy are accuracy of ground control points used in aero triangulation (mean error σ_{gcp}) and accuracy of absolute orientation of photographs in relation to coordinate system (mean error σ_{ao}). Photogrammetric instruction for mapping in scales 1:10 000 and 1:5 000 (ÚSGK 1959) sets following values of mean errors σ_{gcp} = 0.25 m and σ_{ao} = 0.41 m. The basic a priory mean σ_b error is calculated according to law of error propagation (5).

$$\sigma_b = \sqrt{\sigma^2 + \sigma_{gsp}^2 + \sigma_{ao}^2} = \sqrt{0.41^2 + 0.25^2 + 0.41^2} = 0.63\,[m] \quad (5).$$

A slope of terrain also decreases accuracy of stereophotogrammetric measurement. Thus, re-sultant mean error of stereophotogrammetricaly measured contour lines can be derived from equation (6). You can see the analogy of equation (6) and (2). σ_b represents the value of mean error on a flat surface, parameter b represents the influence of slope, α is a slope angle. Maximum of allowed deviation $d_{max} = 2 \cdot \sigma$.

$$\sigma = \sqrt{\sigma_b^2 + (b \cdot tg\alpha)^2} \quad (6).$$

Coefficient b = 4.2 (KUČERA 1961). It is the same value as for uncovered terrain in topographical mapping. **Table 2** shows d_{max} for stereophotogrammetricaly measured maps in scale 1:10 000.

But this maximum allowed deviation is relevant just in uncovered areas, because stereophotogrammetric measurement needs a direct visibility to the terrain. There have to be used combinations with terrestrial mapping for covered areas. Stereophotogrammetric method can be combined with topographical mapping in areas of deep forests (as it was used for forest areas larger than 25 hectares for map 1:10 000 – ŠÍMA and EGRMAJEROVÁ 2004). There are just index contours measured photogrammetricaly and the rest of terrain is measured by topographical mapping. Other

Slope in %	Slope in °	d_{max} in meters (uncovered terrain)
0-5	0	1.3
5-10	2.25	1.4
10-20	4.5	1.8
20-30	9	2.4
30-40	13.5	3.0
40-50	18	3.7
50-60	22.5	4.5
More than 60	More than 22.5	$d_{\max} = 2 \cdot \sqrt{0.63^2 + (4.2 \cdot tg\, a)^2}$

Tab. 2 Maximum allowed elevation deviations of contour lines of topographic maps in scale 1:10 000 (stereophotogrammetricaly measured)

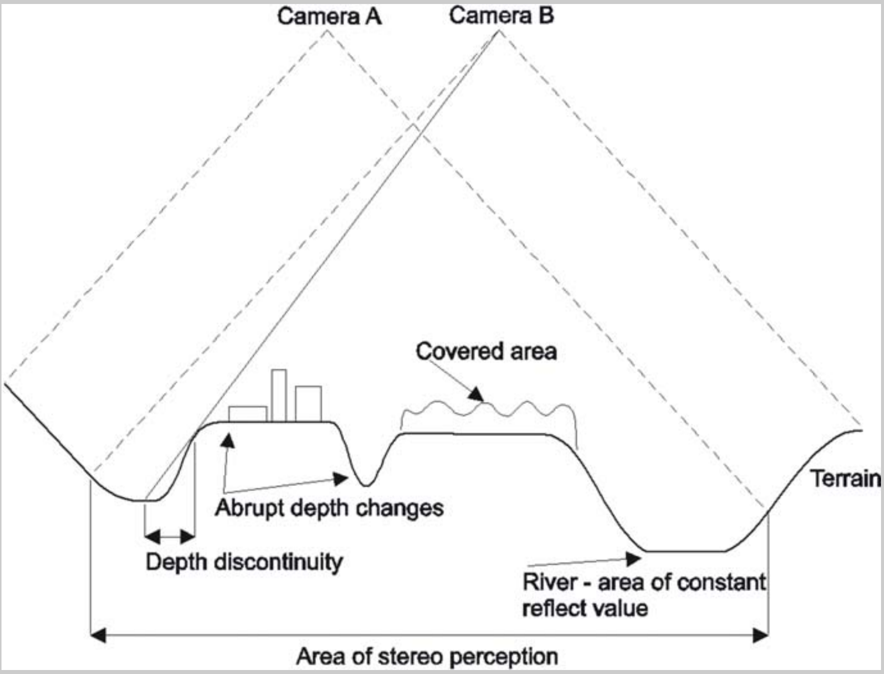

Fig. 5 Areas of decreased accuracy

method, which can be used in smaller forests, is based on measuring contour lines at the top of trees and reducing their average height. Maximum allowed deviation in these areas correspond to d_{max} from topographical mapping.

Following list shortly describes types of areas where it is possible to expect an aggravation of DTM vertical accuracy:

a) Covered areas: vegetation (dense forests, bushes, crops, grass, etc.). The problem is how to interpret the bare Earth under vegetation.

b) Abrupt depth changes (slopes, valleys, urbanized areas).

c) Depth discontinuities – places which are not visible from both camera positions (steep slopes, deep and narrow valleys, densely urbanized areas).

d) Areas with constant reflex value – missing textures (snow, water areas, airports, etc.), overexposed areas (such as a limestone mine in a forest). Only the boundary can be interpreted. This shows problems when the elevation or slope of the area is not constant.

e) Combinations of above mentioned.

Figure 5 depicts reasons of aggravated accuracy in each type of area. The aggravation comes from the visibility angles from two positions of stereophotogrammetric camera (A and B), from which photographs of the area of interest has been shot:

Also season of data acquiring is important for resultant DTM, because the vegetation cover varies during the year. Better ortophoto colors (dense and green vegetation cover) are sometimes preferred, unfortunately for DTM quality. Contrariwise, final user of DTM can use the ortophoto as good source for predicting of a), d) and partially b) and c) type of area with decreased accuracy.

There can be two types of primary representation of DTM created by stereo measurement. First type comes from analog stereophotogrammetry and corresponds to the same representation what comes from topographical mapping. In a case of digital measurement, the primary representation is a set of irregularly distributed 3D points with added break lines, which can be triangulated to TIN.

LIGHT DETECTION AND RANGING

Aerial LIght Detection And Ranging (LIDAR) is a method which is similar to photogrammetry, but active sensor is used. Principle of LIDAR is based on an active laser beam, which is emitted by sensor to the ground, where it is reflected back. The LIDAR sensor records the time difference between the emission of the laser beam and the return of the reflected laser signal to the sensor. Unique attribute of LIDAR is that many returned beams can be recorded. Therefore both first and last return can be acquired at once. Also all intermediate returns are acquired and recorded. See F**igure 6** for schema of acquiring returns.

The data recorded from LIDAR is called a point cloud[11]. Digital terrain model (DTM)

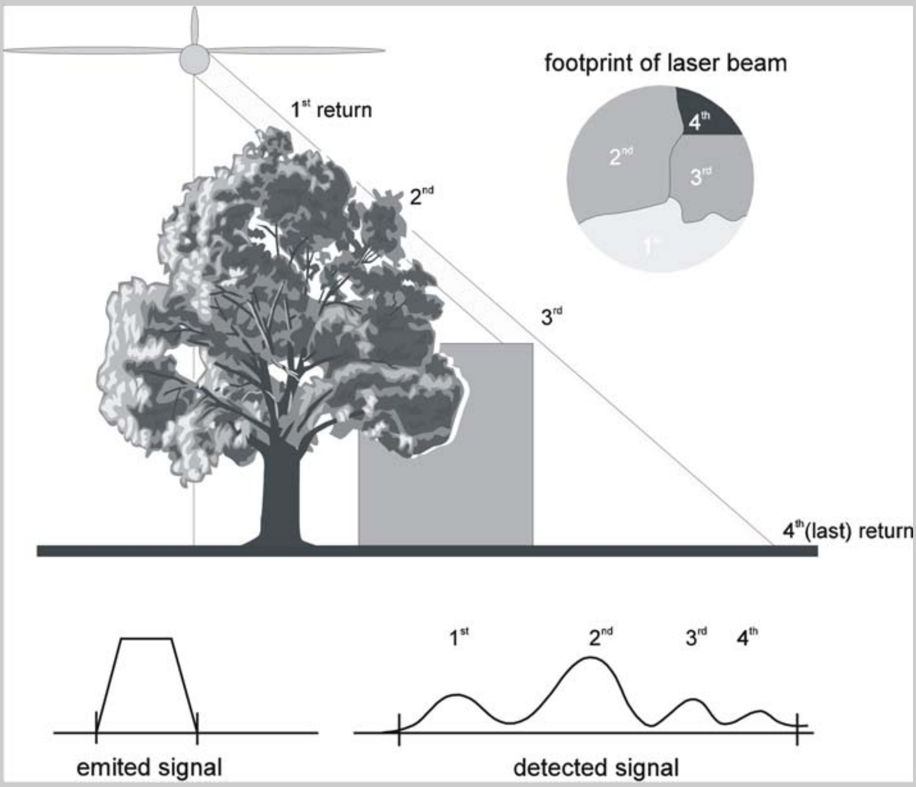

Fig. 6 Principle of laser beam emitting and detecting (RAUCH 2006)

can be derived from point cloud by separating last returns and applying specific filtration methods to them. These methods filter out such last returns which are not returns of bare Earth. The principle of these filters is that a (smooth) surface[12] is interpolated through all of last returns. Those returns, which are too far (a threshold value is used) from the surface are filtered (**Fig. 7**). There is a necessary assumption, that majority of last returns represent bare Earth[13].

Digital surface model (DSM) is constructed from first returns. A filtration method can be also used for erasing some errors and e.g. birds, but usually nothing should be between the sensor and DSM. See more about filtration methods e.g. in DOLANSKÝ 2004.

See more about principles of LIDAR e.g. in DOLANSKÝ 2004, NOAA 2006 or CSANYI 2006.

USACE 2002 describes vertical accuracy of LIDAR data is 0.15 m and decreases by 0.1 m every 1000 m above 2500 m flight height[14]. The important aspect is that the vegetation cover does not have as strong influence to vertical precision. As long as at least an amount of last returns is from the ground, the DTM can be extracted using morphology filters. When no last return is from the ground, the DTM cannot be extracted. But the LIDAR ability "to see" under the vegetation is much better than stereophotogrammetry, because value of a resultant pixel in stereophotogrammetry is an average of incident light intension and colour. Contrariwise footprint of LIDAR beam has several values, depending on number of returns (**Fig. 6**).

Horizontal resolution of a surface created by LIDAR is 1/1000 of flight height, because the laser light is emitted with an angle of 1 mrad. E.g. the footprint has a diameter of 1 m

[11]The point cloud, which covers the area of interest is irregular, because of different LIDAR scanner constructions and because just one laser beam is emitted in a moment. See more about LIDAR construction in DOLANSKÝ 2004 or RAUCH 2006

[12]The surface type varies depending on used software

[13]This condition does not have to be true e.g. in forests. Last return in dense vegetation does not have to be equal to DTM, in a case there is no visibility between the sensor and terrain. But this method has still better results than stereophotogrammetry in these areas, because the sensor covers the area more densely and from much more positions than photogrammetry

[14]But under 2 500 m flight height it cannot be much better

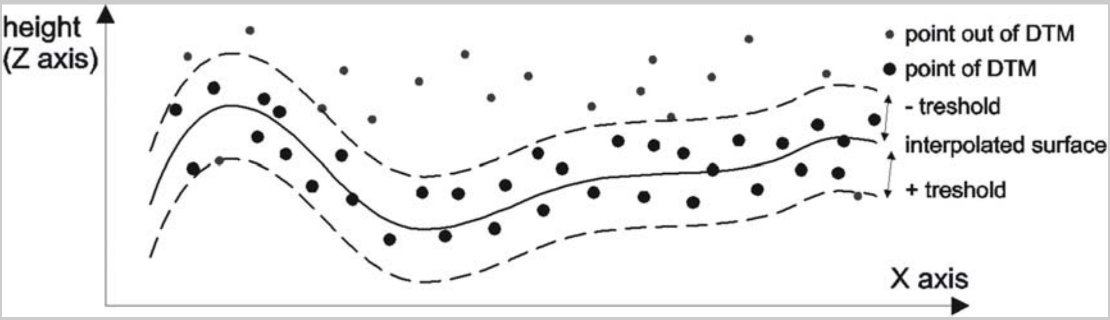

Fig. 7 Filtering points out of DTM

at a flight height of 1000 m (2.5 m resolution for 2500 m flight height by analogy). More about LIDAR accuracy is described in mentioned USACE 2002 or e.g. DIEDERSHAGEN et al. 2004. Nowadays even systems with 0.5 mrad emitter angle have been developed, see more e.g. RIEGL Laser Measurement Systems (2008).

Mentioned vertical accuracy has been proved for example by CSANYI 2006. The report describes a test of LIDAR accuracy, using control points with known coordinates – special "LIDAR targets" (measured by GPS with horizontal precision 0.01 - 0.02 m and vertical precision 0.02 - 0.03 m). The test consisted of overlapping flights above test area measuring LIDAR data including targets.

Described average height differences between known GPS coordinates and data measured by LIDAR were 0.1 m (based on several test flights). The maximum detected errors were 0.2 m. *"The test results have shown that at a LiDAR point density of 5 pts / m^2, 10 cm horizontal accuracy and 2-3 cm vertical accuracy of the extracted road surface can be achieved using the designed targets. To provide this high level of accuracy, a dense and well-distributed network of targets is needed"* (CSANYI 2006).

Primary representation of a DSM / DTM derived form LIDAR data is a filtered cloud of 3D points, through which is possible to interpolate usually a TIN.

DTM SUITABILITY FOR GEOMORPHOLOGIC ANALYSIS - DISCUSSION AND CONCLUSION

Usual sources of DTM were topographic maps in the past. The elevations displayed on these maps were acquired by topographic mapping or analogue stereophotorammetry. The DTM was consequently gathered from contour lines and its primary digital representation is thus composed of geometric primitives. Nowadays it is common to get the data directly from digital stereophotogrammetry, where TIN is the primary representation. The possibility to get the LIDAR data (cloud of points) is still rare, even if it become common in the future.

Note: the other relatively new technology – global positioning systems (GPS) – is not advisable because of its impossibility to receive the satellite signal in densely covered areas. But it can take a place together with classic terrestrial geodesy (which gives us back on topographic mapping).

It is important to know, what was the method of DTM data acquisition, because, these methods strongly influent accuracy and quality of resultant DTM. Topographic mapping and stereophotogrammetry – two usual sources – are usually less accurate in geomorphologicaly interesting areas (even if each by other way) because steep slopes are common in these areas and they are also usually covered by vegetation. Control profiles or distinct point measurement can be used for local DTM improvements. On the other hand, laser scanning is still an expensive way to acquire a DTM. Therefore above described characteristics of DTM accuracy can be helpful for making decisions of which DTM to use. Sometime the absolute accuracy is not as much important as a relative trend of relief in area of interest. Therefore less accuracy but not as much expensive DTM from e.g. topographic mapping can be very helpful.

A summary of expectable accuracy of particular methods follows. Generally we can say that we can expect accuracy (described by maximum allowed elevation deviations) from 1,4 m to 11 m for topographically acquired data and accuracy from 1,3 m to 4,5 m for stereophotogrammetrically acquired data, where the best accuracy we can expect on flat uncovered terrain, meanwhile the worst accuracy is in covered areas with steep slopes. It implies that it is not possible to describe all the data with one accuracy number. Rather it is possible to understand the accuracy as a function of slope, vegetation cover and other residual effects.

Better situation is in a case of LIDAR, where the accuracy (described usually as height differences between measured LIDAR height and known GPS height) depends mostly on flight height, but not so much on vegetation cover and slope (but even in a case of LIDAR data, the vegetation can have such a density, then it is not possible to extract DTM ~ as described above). The LIDAR independency on vegetation cover and terrain slope causes that the produced data have homogenous accuracy. For the flight height 2 500 m and lower can be reached vertical accuracy about 0.15 m and horizontal 2 - 5 times worse.

The method of data acquisition determines also the primary digital representation of surface (geometric primitives, TIN or cloud of points). The next problem is a data conversion (usually interpolation) to raster – the representation usually used for DTM representation in geomorphology. Each conversion/interpolation method potentially aggravates the data accuracy. There can be found works (e.g. BONK 2003, FRANKE 1982, MITÁŠ and MITÁŠOVÁ 1988, PACINA 2006 and many others), whose describe both the precision and accuracy of particular methods. But it is important to distinguish between accuracy (difference between real terrain and interpolated surface) and inner precision of a method (difference between primary digital representation and interpolated surface).

In the future digital elevation models combined from different acquisition methods are going to be used. New measurements do not cover the Earth surface continuously but are dependent of the importance of particular area. Cities and surrounding areas, including traffic infrastructure are now precisely measured by different methods (mostly stereophotogrammetry and LIDAR). These data can be after combined into DTM of heterogeneous quality. Well developed metadata would be necessary. Also data consistency along boundaries of areas with more accurate DTM would be a problem. There can be used e.g. a modification of boundary matching algorithm described in JEDLIČKA 2006, taking the boundary of more precise model as a reference.

THE SITUATION IN THE CZECH REPUBLIC

Over 80 % of the area of the Czech Republic was primarily covered by contour lines from stereophotogrammetric measurement in 1957 – 1971. The rest 20 % was simultaneously mapped in topographic way. Resultant measurements were graphically portrayed on printing masters of Topographic map in scale 1:10 000. Afterwards they were adopted into Base map of the Czech Republic in scale 1:10 000. Portrayed contour lines were scanned and vectorized in years 1994 – 2000. A result of the vectorization was DTM of Fundamental Base of Geographic Data (original acronym: ZABAGED). Works on accuracy improvements in neighborhood of terrain break lines of DTM and in flood plains succeed in years 2005 – 2008. Mean elevation error smaller than 1 m in open (uncovered) terrain is expected as the result.

First LIDAR measurement for purposes of acquiring data for state surveying of DTM and DSM in the Czech Republic was realized as an experiment in an area of 500 km^2 in year 2006. The flight height was 2750 m and average distance among points in a cloud was 2,4 m. Results are processed and will be evaluated during years 2007 - 2008. There is starting a complete LIDAR measurement of Czech Republic on autumn 2009.

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