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THE ACCURACY OF LiDAR MEASUREMENTS FOR THE DIFFERENT LAND COVER CATEGORIES

Daniela IORDAN, Gabriel POPESCU

University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, 011464, Bucharest, Romania; Phone: +4021.318.25.64, Fax: + 4021.318.25.67

Corresponding author email: gabrielpopescu2013@gmail.com

Abstract

The paper aimed to present, for the different land cover categories, the accuracy of LiDAR measurements obtained with a light detection and ranging dataset from a test area of the hydrographical basin Somes-Tisa in Romania. It is presented the geometric geolocation accuracy of LiDAR footprint for few land cover categories, utilizing an UAV configuration that supports a sensor designed to scan the surface of the Earth, a DGPS and INS/IMU system. There are presented the geometric accuracies, for LiDAR footprints on the ground, as a relationship between the input parameters, which include errors of the orbital state, attitude information of the UAV and the look vector errors of the active sensor (LiDAR scanner), that give us the coordinates of the point of intersection of the line of sight scanning system and the Earth's surface as a function of: terrestrial ellipsoid surface, UAV position, UAV attitude (spatial situation) and the orientation of the LiDAR scanner. As a conclusion, the paper proposes the vertical accuracy requirements that are recommended when analyzing elevation data generated using airborne light detection and ranging or laser technology, because vertical accuracy is the principal criterion in specifying the quality of elevation data, and vertical accuracy requirements depending upon the intended users applications.

***Key words**: Geomatics, LiDAR, Remote sensing, UAV.*

INTRODUCTION

As is well known, LiDAR (Light Detection and Ranging) is a remote sensing instrument that measures distance to an object by emitting timed pulses of light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to a distance. LiDAR scanner emits rapid streams of laser pulses and distance (range) between object and scanner is measured by computing the time to travel of the laser pulse from the scanner to the object and back. Coordinates of each reflected laser pulse is computed combining: distance or range, scan angle, sensor location and sensor orientation.

Studies have shown that LiDAR errors are significantly affected by various ground cover categories. Because natural vegetation or crops can limit ground detection, tall dense forests, tall grass or agricultural crops tend to cause greater elevation errors than unobstructed terrain. Errors measured in areas of different ground cover also tend to be distributed differently from errors in unobstructed terrain.

For these reasons, international standard requires open terrain to be tested separately from other ground cover types. Testing over any other ground cover category is required only if that category constitutes a significant portion of the project area deemed critical to the customer.

Varying types of topography (such as mountainous, rolling, or flat terrain) within a project may affect the accuracy at which the elevation surface can be modeled. Also, for many applications, the accuracy requirement in high-relief terrain may be less than that for flat terrain. In such situations, it may be preferable to specify different accuracy requirements for the various terrain types and to design separate tests for each (ASPRS LiDAR Committee, 2004).

The fundamental vertical accuracy is the value by which vertical accuracy can be equitably assessed and compared among datasets. The fundamental vertical accuracy of a dataset must be determined with check points located only in open terrain where there is a very high probability that the sensor will have detected the ground surface. It is obtained utilizing

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standard tests for Root Mean Square Error (RMSE).

LiDAR platforms, shown below in Figure 1, can be: fixed position (Fig.1a), mobile (Fig.1b) and airborne (Fig.1c, the most popular: helicopters, airplanes, UAVs).

a) fixed position b) mobile

c_1) helicopter c_2) airplane c_3) UAVs

Figure 1. Types of LiDAR platforms

A typical LiDAR system, presented in Figure 2, consists of three main components: a GNSS system to provide position information, an INS/IMU for attitude determination, and a laser unit to provide range (distance) information from the laser beam firing point to the ground point. In addition to range data, modern LiDAR systems can capture intensity images over the mapped area.

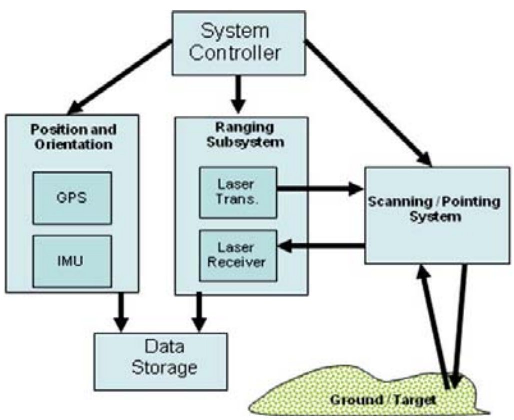

Figure 2. Diagram of a typical LiDAR system (NGA Standard, 2009).

Below, in Figure 3, is presented a simplified diagram of the processes LiDAR data pass through before reaching the end user.

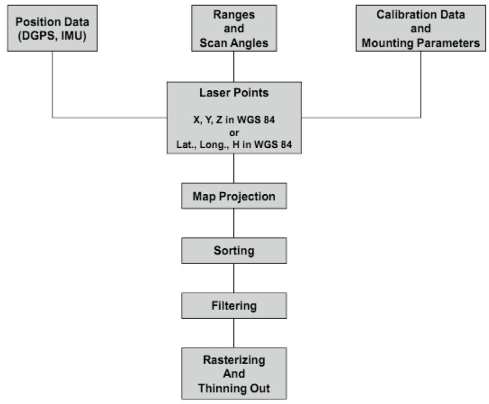

Figure 3. Diagram of the processes LiDAR data pass through before reaching the end user (ASPRS 2004)

The transformation between the footprint on the image and the ECEF footprint is expressed in terms of a series of consecutive matrix transformations applied to the line of sight vector of LiDAR. Finally, for any scan footprint, we obtain ECEF coordinates (by intersection of the scanner's view line with the ellipsoid used to model Earth) and then geodetic coordinates (geodetic longitude and latitude).

Recently, improvements in small scale positioning technology have enabled the use of Unmanned Aerial Vehicles (UAVs) as a close range sensing platform offering a distinctive combination of very high resolution data capture at a significantly lower survey cost to traditional platforms.

Current research into the use of UAVs, as a 3D data-capture platform, includes application specific use in a variety of different fields ranging including for agriculture crop monitoring and forests monitoring.

There are many factors that affect the accuracy of coordinates derived from a LiDAR system. These errors which can be summarised into 17 error components which will occur in every system were modeled by Luke Wallace et.al. in 2011. These error components can be described as:

- 3 errors existing in the measurement of the absolute position;

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- 3 errors existing in the measurement of UAV orientation;
- 6 errors caused by the inaccurate calibration of the system affecting the bore sight angles and lever arm offset;
- 3 Internal LiDAR system errors occur in measurements of range and the two L encoder angles measured from the UAV;
- 2 errors due to divergence of the laser beam which propagate in the horizontal direction and elevation angle measurements within the laser scanner reference frame.

These error components can be propagated through the functional model of the LiDAR system equation enabling the magnitude of the error in the final coordinates of a point to be determined.

The notations of all parameters n (known and unknown) from mathematical relation below are shown in the Figure 4 (Ki In Bang, Ayman F. Habib, 2008).

$$\vec{X}_G = \vec{X}_o + R_{yaw,\ pitch,\ roll}\ R_{\Delta\omega,\ \Delta\phi,\ \Delta\kappa}\ \vec{P}_G + R_{yaw,\ pitch,\ roll}\ R_{\Delta\omega,\ \Delta\phi,\ \Delta\kappa}\ R_{\alpha,\ \beta} \begin{bmatrix} 0 \\ 0 \\ -\rho \end{bmatrix}$$

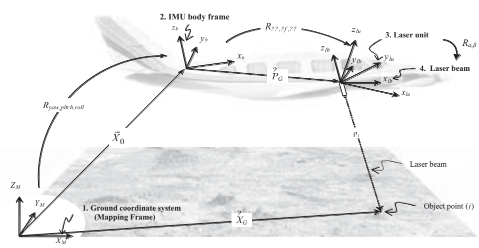

Figure 4. Relationship between LiDAR scanner, INS/IMU, GPS and their reference systems

Commercial vendors have fostered development of multiple-return systems to penetrate vegetation canopies in order to receive and identify more bare earth returns in vegetated areas. To derive bare earth models, LiDAR returns representing vegetation and human made features are identified and eliminated using bare earth filtering techniques. In many cases, this ancillary vegetation information is simply discarded. However, for many ecological applications, 3D vegetation information or interactions between vegetation and topography are most important. LiDAR has been used in several studies involving the 3D vegetation structure including estimation of stand height, total above ground biomass, foliage biomass, basal area, tree density, canopy base height, and canopy bulk density and at resolutions where even individual tree characteristics can be measured (Stoker J.M., Greenlee S.K. et. al., 2006).

MATERIALS AND METHODS

In order to obtain the accuracy of LiDAR measurements for the different land cover categories were used airborne LIDAR data which were collected for an area of 100 km², comprising the northwest zone of Somes-Tisa hydrographic basin, where in terms of land use the sub-basin Crasna is dominated by agricultural land.

The data were collected in 2013 and have been processed and interpreted in 2014, based on author's doctoral thesis entitled "Application of laser technologies in topo-graphical survey of Somes-Tisa hydrographic basin" (Iordan D., 2014).

UAV used for data collection in studied area is classified as a micro UAV also known as hexacopter. This UAV is categorized as micro UAV because it has weight below than 5 kilograms and endurance hour less than one hour. Unmanned aerial hexacopter used has six blades where three blades rotate in clockwise direction while the other three blades rotate in counter-clockwise direction.

RESULTS AND DISCUSSIONS

LiDAR accuracy is generally stated in vertical direction as the horizontal accuracy is indirectly controlled by the vertical accuracy. This is also due to the fact that determination of horizontal accuracy for LiDAR data is difficult due to the difficulty in locating Ground Control Points (GCPs) corresponding to the LiDAR coordinates.

Prior to calculating the data accuracy, few steps should be taken, as follows:

- Separate checkpoint datasets according to important variations in expected error such as by land cover class;
- Edit collected checkpoints to identify, remove or minimize errors and blunders;
- Interpolate the elevation surface for each checkpoint location;

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- Identify and eliminate LiDAR sensor systematic errors and blunders in the LiDAR data processing.

The vertical accuracy is determined by comparing the Z coordinates of data with the truth elevations of a reference (which is generally a flat surface).

The vertical accuracy is stated as $RMSE_z$ (root mean square error) and given by:

$$RMSE_z = \sqrt{[\Sigma (z_{data,i} - z_{check,i})^2 / n]} \quad (1)$$

It is assumed that systematic errors have been eliminated as best as possible. If vertical error is normally distributed, the factor 1.9600 is applied to compute linear error at the 95% confidence level (Andre Samberg 2005).

Therefore, vertical accuracy, noted A_z, reported according to the American standard NSSDA (National Standard for Spatial Data Accuracy) shall be computed by the following formula:

$$A_z = 1.96 \cdot RMSE_z \quad (2)$$

(This accuracy is called fundamental vertical accuracy when the $RMSE_z$ is determined for a flat, non-obtrusive and good reflecting surface).

According with NSSDA, horizontal accuracy for $RMSE_{xy}$:

$$\mathbf{RMSE_x} = \sqrt{[\Sigma (\mathbf{x}_{data,i} - \mathbf{x}_{check,i})^2 / \mathbf{n}]} \quad (3)$$

$$\mathbf{RMSE_y} = \sqrt{[\Sigma (\mathbf{y}_{data,i} - \mathbf{y}_{check,i})^2 / \mathbf{n}]} \quad (4)$$

where:

- $\mathbf{x}_{data,i}$, $\mathbf{y}_{data,I}$ are the coordinates of the $\mathbf{i}^{th}$ check point in the dataset data;
- $\mathbf{x}_{check,i}$, $\mathbf{y}_{check,I}$ are the coordinates of the $\mathbf{i}^{th}$ check point in the independent source of higher accuracy;
- **n** is the number of check points tested;
- **i** is an integer ranging from 1 to n.

Horizontal error of a point **i** is defined as $RMSE_{xy}$ with formula:

$$RMSE_{xy} = \sqrt{RMSE_x^2 + RMSE_y^2} \quad (5)$$

It is assumed that systematic errors have been eliminated as best as possible. If error is normally distributed and independent in each the x- and y-component and error, the factor 2.4477 is used to compute horizontal accuracy at the 95% confidence level (Andre Samberg, 2005).

If we consider the measurements of the same accuracy in plan xy, than $RMSE_x$=$RMSE_y$, and the $Accuracy_{xy}$, noted A_{xy}, shall be computed according to NSSDA, by the formula:

$$A_{2D} = A_{xy} = 1.73 \cdot RMSE_{xy} \quad (6)$$

The various sensor components fitted in the LiDAR instrument possess different precision. For example, in a typical sensor the range accuracy is 1-5 cm, the GPS accuracy is 2-5 cm, scan angle measuring accuracy is 0.01rad, IMU accuracy for pitch/roll is < 0.005° and for heading is < 0.008° with the beam divergence being 0.25 to 5 mrad. However, the final vertical and horizontal accuracies that are achieved in the data is of order of 5 to 15 cm and 15-50 cm at one sigma.

The total spatial accuracy of a LiDAR footprint is given by the formula:

$$A_{3D} = A_{xyz} = \sqrt{A_{xy}^2 + A_z^2} =$$

$$= \sqrt{(1.73 \cdot RMSE_{xy})^2 + (1.96 \cdot RMSE_z)^2} \quad (7)$$

The accuracy of LiDAR measurements discussed in this paper refers to absolute vertical accuracy, which accounts for all effects of systematic and random errors. For some applications of LiDAR elevation data, the point-to-point (or relative) vertical accuracy is more important than the absolute vertical accuracy.

Relative vertical accuracy is controlled by the random errors in a dataset. The relative vertical accuracy of a dataset is especially important for derivative products that make use of the local differences among adjacent elevation values, such as slope and aspect calculations. Relative vertical accuracy can be difficult to measure unless a very dense set of reference points is available.

There may be error in the laser range measured due to time measurement error, wrong atmospheric correction and ambiguities in target surface which results in range walk.

Error is also introduced in LiDAR data due to complexity in object space (e.g., sloping surfaces leads to more uncertainty in X, Y and Z coordinates). Further, the accuracy of laser

range varies with different types of terrain covers.
One of the paper's results was to estimate the error associated with the LiDAR system elevation, where one of the main objectives in specifying parameters for data collection (flight height, the travel speed, footprint) is to achieve an appropriate density of LiDAR impulses. After the labelling category of land cover, and if it was done correctly, we observed that the error altitude varies according to the category of land cover (Table 1).
The variation of the vertical accuracy was evaluated for nine categories of land cover.
The values of root mean square error ($RMSE_z$) has varied from minimum 4.5cm (for straw) to a maximum of 23.4cm (for canopy). The differences values from Table 1 are graphically represented below in Figure 5.

Table 1. Characteristic values of $RMSE_z$ and A_z for 5646 points of Land Cover Categories

Crt. No.	Land cover type	Total number of points tested	Differences (m) ($Hp._{LiDAR}$-$Hp._{ground}$) Value Min. / Value Max.		The average value (m)	$RMSE_z$ (cm)	Vertical Accuracy (cm)
1	Canopy	858	-0.600	0.598	-0.013	23.4	45.8
2	Road of asphalt	16	-0.161	0.562	0.070	21.5	42.1
3	Road of land	108	-0.460	0.588	-0.009	13.3	26.0
4	Road of stone	16	-0.355	0.130	-0.071	12.4	24.4
5	Gardens, vegetables	15	-0.246	0.047	0.004	9.5	18.6
6	Nonproductive and uncultivated	867	-0.595	0.528	0.004	9.5	18.6
7	Wheat, straw	321	-0.204	0.336	-0.004	4.5	8.9
8	Corn	2053	-0.520	0.580	0.001	5.2	10.1
9	Slopes	1392	-0.582	0.593	-0.007	14.8	29.0
Total		5646	-0.600	0.598			

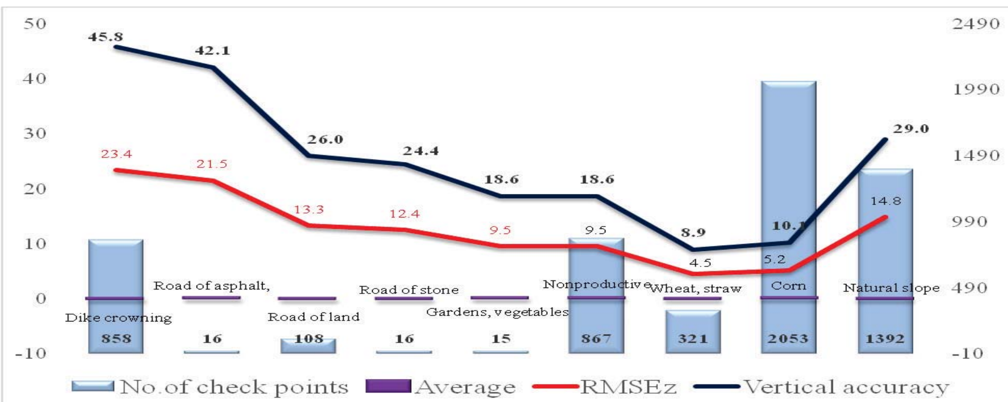

Figure 5. The graph of $RMSE_z$ and vertical accuracy in centimetres, depending on the Land Cover Category

CONCLUSIONS

LiDAR-based elevation surveys are a cost-effective means for mapping topography over large areas. Post-processing techniques are applied to remove vegetation and reveal the bare-earth elevations. In the recent years, LiDAR hardware and processing technologies have improved greatly. LiDAR surveys are now cost-competitive with traditional aerial topographic surveys and offer the capability to produce very high resolutions (potentially over 50 points / m, with vertical accuracy for airborne systems <10 cm).
LiDAR survey data may not replace traditional ground-based survey for applications that require centimeter or sub-centimeter accuracy, but the data available from these surveys, using an UAV, may be perfect for many engineering applications.

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We have used a set of four accuracy standards and guidelines, as follows:

- Guidelines for digital elevation data;
- ASPRS guidelines – Vertical accuracy reporting for LiDAR data;
- Guidelines and specifications for flood hazards mapping;
- Geospatial positioning accuracy standards.

Accuracy typically assessed is for 5 different land cover classes: bare-earth, weeds and crops, scrub/shrub, forest and urban, and the results are graphically presented in Figure 6.

Fundamental vertical accuracy was commonly reported at 95% confidence level of root mean square error (i.e., RMSE = standard error).

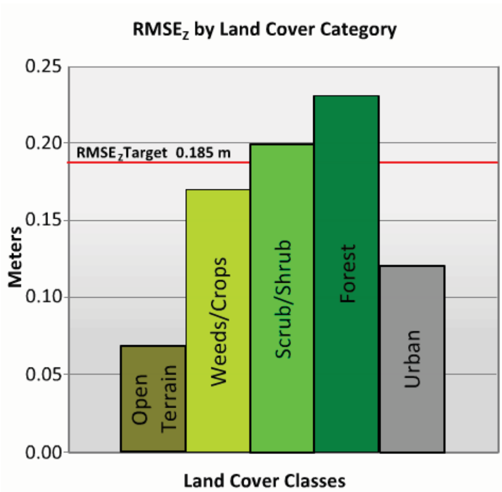

Figure 6. The graph of $RMSE_z$ depending by the Land Cover Category

LiDAR pulses can hit several objects before being reflected and cannot penetrate opaque objects (such as stems, branches, leaves) but can go between the leaves and hit the ground or other points with lower elevation than the first hit surface (first return)

Current LiDAR systems can detect secondary targets and record multiple elevations for each pulse and the last object recorded for a pulse is called last return.

The feature that allows recording multiple returns allows for determination of trees or crops height, presented in Figure 7.

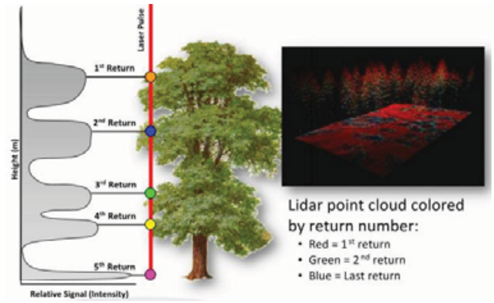

Figure 7. Multiple returns LIDAR pulses for determination of trees or crops height.

Multiple returns LiDAR pulses are based on relative signal strength/intensity recorded by the sensor.

Vertical accuracy is assessed by selection and measurements of checkpoints using survey grade GPS and/or conventional survey equipment. Vertical error is the difference between the elevation determined using LiDAR and using DGPS of the same checkpoint.

Checkpoints must be distributed across investigated area, and includes as many flight lines as possible and characterize the dominant land cover categories within the area.

It is preferable to have at least 20 checkpoints / land cover category, located on flat areas for minimizing horizontal errors.

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