

# The use of modern technologies in the surveying field

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**Abstract.** In order to achieve or complete the 1: 1.000 scale situation plan and the digital terrain model for the Timișoara - Sibiu highway section, and given the difficult access conditions in the project area, it was decided to use photogrammetric techniques for extraction of spatial information needed for mapping. In order to achieve the mapping requirements at a scale of 1: 1.000, the following activities were performed: Realization of the geodetic support network; Realization of the aerial photography project; Making pre-marking points in areas without clear details or other location possibilities; Simultaneous aerial photography of sub-blocks at different flight heights to ensure a 12 cm pixel and simultaneous laser scanning with LiDAR system; Identification of marking and pre-marking points on the subblock frames; Performing GPS measurements to determine the coordinates of landmarks and photogrammetric pre-marking; LIDAR data processing using permanent GPS stations to obtain coordinates in the ETRS89 system and transform them into the STEREO70 system and Black Sea reference plan 75; Calibration of LIDAR data; Filtering LIDAR data; Realization of aerotriangulation on subblocks or bands; Stereo restitution of planimetric and altimetric details for 1: 1.000 scale (3D mode); Transforming 3D plans into 2D plans; Editing and elaborating topographic plans.

## 1 Introduction

Recently, the acquisition of topo - geodetic data using modern geomatic technologies such as LiDAR [1] and GNSS is increasingly used due to the rapid evolution of positioning and measurement technologies [2]. If the research requires high resolutions aerial photogrammetric techniques are very suitable and therefore their use in combination with LiDAR technology is becoming more widespread or with global navigation satellite system (GNSS) techniques [3-5].

Some studies have shown widespread use of unmanned aerial vehicles [6, 7] (UAVs), a technology that is constantly growing in many applications in various fields [8]. The use of UAVs or remotely piloted aircraft systems (RPAS) has recently been extended to civilian

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applications, including mining [9], precision agriculture [10], urban development [11], environmental protection, forestry [12, 13], etc.

In order to achieve and / or complete the 1: 1000 scale situation plan and the digital terrain model – DTM - for the Timisoara - Sibiu highway section, and given the difficult access conditions in the project area, it was decided to use photogrammetric techniques for extraction of spatial information needed for mapping. Also, the photogrammetric method produces a greater coverage of the proposed area, which allows the designer to have an overview of the design area and choose optimal solutions.

Thus, in order to meet the mapping requirements at a scale of 1: 1000, the following activities were performed:

- Realization of the geodetic support network for the designed route;
- Carrying out the aerial photography project on strips or blocks depending on the terrain relief and the configuration of the designed route;
- Making pre-marking points in areas without clear details or other location possibilities;
- Simultaneous aerial photography of sub-blocks at different flight heights to ensure a 12 cm pixel and simultaneous laser scanning with LIDAR system;
- Identification of marking and pre-marking points on the sub block frames;
- Performing GPS measurements to determine the coordinates of landmarks and photogrammetric pre-marking;
- LIDAR data processing using permanent GPS stations to obtain coordinates in the ETRS89 system and transform them into the STEREO70 system and Black Sea reference plan 75
- Calibration of LIDAR data based on levelling determinations in several plane control areas;
- Filtering LIDAR data to eliminate the points registered on vegetation, lakes, and buildings;
- Realization of aero-triangulation on sub-blocks or strips, using additionally elevation points determined in the LIDAR system;
- Stereo restitution of plan metric and altimetry details for 1: 1000 scale (3D mode)
- Transforming 3D plans into 2D plans for editing and mapping
- Editing and elaborating topographic plans with conventional signs and toponymy

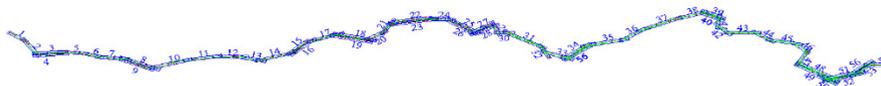
The following equipment was used to perform the photogrammetric activities:

- Diamond DA42 MPP model LMS Q560
- LIDAR RIEGL Laser Scanner Pod System BP560-ID with 2xDR560-RD, IGI INS / FMS
- IGI DigiCAM aerial camera with 6.8 micron sensor,  $f = 50.256\text{mm}$
- Stereo-playback software: DVP and ArcGDS
- DVP and AeroSys aero-triangulation software for compensation
- LIDAR data filtering software: GeoTools
- 3D system return equipment with passive computer glasses and CRT monitor with Z-Screen system, active 3D glasses and stereo ready 3D LCD monitor (8 systems)

Based on these considerations, an aerial photograph was taken (fig.1) of the projected route with an average pixel resolution of 12-14 cm to ensure the accuracy required for the 1: 1000 plan (a graphic precision for writing the plans of 0.2 mm is ground for plans at a scale of 1: 1000 a resolution requirement of 20cm).

This resolution allowed us to obtain a plan metric precision of the order of pixel resolution and altimetry of order of 1.3 of the pixel resolution, ie of 16 - 19 cm.

The average flight altitude is between 1100 and 1300m. The flight was performed taking into account that the longitudinal coverage of the frames should be approx. 60%, and the transversal one of 30%. Also, the coverage between the neighbouring lanes was ensured by at least 3 frames. The flight was made in conditions of maximum visibility, in periods without clouds, with maximum brightness.



**Fig. 1.** The aerial photography project.

However, using LIDAR points in the aero-triangulation process, the accuracy on the dimension was significantly improved by two methods:

- use of LIDAR dimension points as a benchmark in aero-triangulation
- the direct use of LIDAR points in the network of quoted points from the returned plan

To cover the route, 59 aerial photography strips were designed (fig.1) which were executed with a specialized photogrammetric plane and the DIGICAM digital camera.

The aircraft was equipped with an airborne DGPS system to accurately determine the coordinates of the image projection centres. It is also equipped with INS / IMU type inertial systems and DGPS equipment.

An additional GPS station near Faget also operated during the flight, which was used to verify the accuracy in case the permanent station in Faget was malfunctioning.

## 2 Description

### 2.1 Camera type and lens

The aerial photography was performed with the DigiCAM digital colour camera. The digital photogrammetric camera used is equipped with all the modern attachments necessary to obtain very good quality frames.

- Built-in FMC (Forward Motion Compensation) linear drag compensation system - which allows the elimination of the drag phenomenon, removes the ambiguity of the details on the frames, due to the movement of the plane in the interval when the shutter is open;
- Inertial Unit of Measurement - IMU for recording residual values of ( $\varphi$ ,  $\omega$ ,  $\kappa$ ) for each frame;
- Airborne DGPS receiver for accurate determination of frame projection centre coordinates.

The objective was calibrated for the visible spectral range. The radiometric resolution was set to 8 bits. The camera lens used has been calibrated, tested, and certified by the camera manufacturer. The calibration certificate demonstrates that the DigiCAM camera type is automatically calibrated using its control software and the image transformation procedure solves all distortion problems.

### 2.2 Identification and aero-triangulation

For the calibration of the frames in the national Stereo70 projection system, marking and pre-marking points were identified on the images, which were accurately determined by

field measurements with GPS technology. They were also read in the aero-triangulation process and compensated so as to obtain the desired determination accuracy.

Through aero-triangulation there is practically an automatic thickening of the corresponding initial landmarks - image so that each stereoscopic model contains points with coordinates in the frame system and in the field system

Following the aero-triangulation process for each frame, external orientation parameters will be determined which will ensure the extraction of information in the stereo coordinate system<sup>70</sup>. To ensure accuracy, we used photogrammetric control points already existing in our database, packed with benchmarks measured after shooting.

To determine the coordinates of the points of the tracking network, GPS determinations were used according to the methodology established by ANCP, respectively determinations were made in the ETRS89 system and they were transformed with the TransdatRO v4.01 program provided by ANCP. In this way, the survey geodetic network was made in a unitary and homogeneous way for the entire highway route.

The field measurements were connected to the basic GPS network through the permanent stations in Sibiu, Deva, Alba Iulia, Faget and Timisoara.

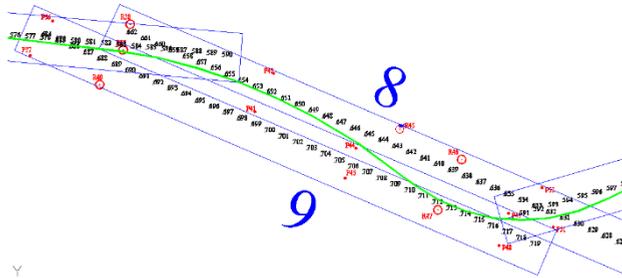
The landmarks were determined plan metrically in the Stereographic 1970 coordinate system and altimetry in the Black Sea elevation system 1975. The landmarks were framed in a unitary network measured with instruments and methods to ensure an interior plan metric accuracy of  $\pm 3$  cm and altimetry of  $\pm 5$  cm. Spotting sketches were made for all photogrammetric landmarks. An example of their coordinate inventory is presented in Table 1.

**Table 1.** Extras from Inventory of location and pre-marking coordinates for the Lugoj - Deva Lot 1.

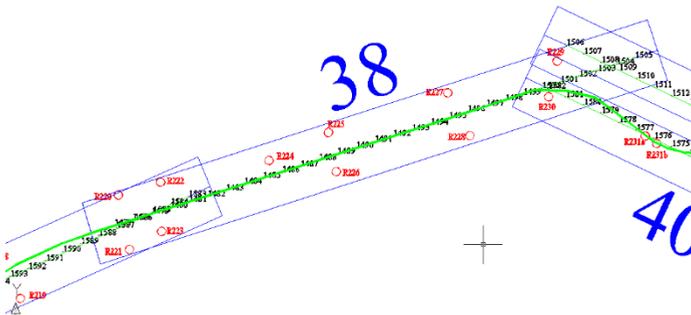
Pct.	E (m)	N (m)	H (m)	LOT
P42	243550.814	482903.340	139.355	LD1
P41	243181.261	482158.785	124.662	
R401	240124.679	482599.603	115.845	
R40	240133.088	482597.887	115.844	
R391	240492.084	483170.414	133.535	
P48	247914.147	479567.575	106.578	
P49	248105.099	480177.412	106.423	
P50	248748.246	480697.509	111.468	
P51	248964.790	479915.347	105.564	
P61	261679.600	483132.356	118.575	
R69	270232.900	483845.584	130.757	
R70	272685.087	483500.726	142.849	
R71	272584.878	483005.067	145.473	
R72	274956.605	483145.323	150.955	
R73	275114.958	482334.326	157.726	
R731	275102.539	482322.286	159.917	

The markers were chosen so that they were arranged at the ends of the strips and on their side edges. It was intended that at a distance of 500 m (approximately 8 frames) there should be a pair of photogrammetric landmarks. An example with their arrangement can be

seen in Figure 2 or Figure 3. It has also been contemplated that the landmarks at the ends of a photogrammetric strip be common landmarks for the next band.

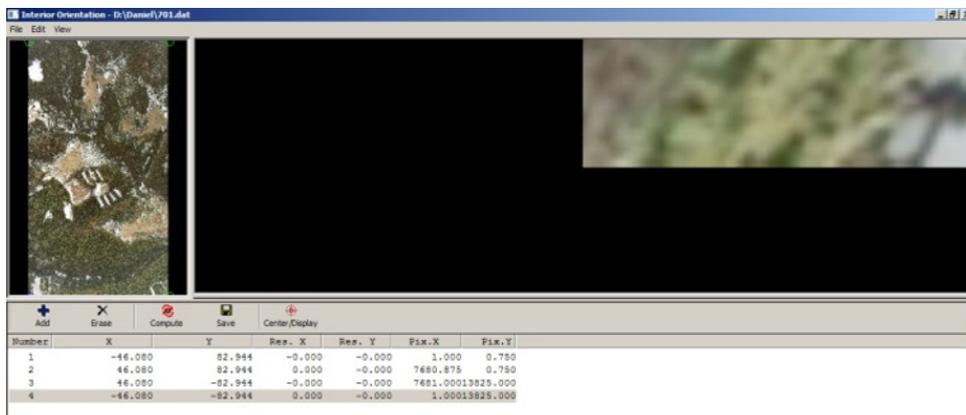


**Fig. 2.** Distribution of photogrammetric landmarks on bands 8-9.



**Fig. 3.** Distribution of photogrammetric landmarks on the band 38.

All photogrammetric processing was performed by operators with over 15 years of experience in drafting photogrammetric plans using DVP software for restitution and Aerosys to compensate for aero-triangulation. The interior orientation was performed semi-automatically, using the Stereo Aerial Triangulation software, developed by DVP Software. After creating a new project and choosing the adjacent frames, the choice of the camera file containing all the parameters necessary for orientation follows. The next step is to score the reference indices on the frame. In this case, they are in the corners of the frame. After that, through the Compute command, the internal orientation is performed (Figure 4).



**Fig. 4.** Achieving interior orientation with Stereo Aerial Triangulation software.

The relative external orientation was further achieved in the Stereo Aerial Triangulation software, by choosing the points of correspondence (or connection) between the models. Point elements or linear intersections were used, which appear on both frames that make up the model. The software does not allow a punctuation of these points in semi-automatic or automatic mode. In principle, at least 15 corresponding points were chosen for each model.

The absolute external orientation supposes the determination of the transformation parameters of the stereo-model in the object space:  $X_0, Z_0, Y_0, \Omega, \Theta, K, \lambda$ . In order to comply with the conditions of co-planarity and collinearity, support elements from the object space are used since the previous stages. Pre-signalled support points that are well defined geometrically and have unmistakable radiometric values can be used, being designed to be visible from all directions of aerial photography (the chosen landmarks are part of this category). The support points (landmarks) must be evenly distributed in the image plane, independent of the informational content of the images and their scale and easy to represent in two or three dimensions. These can be natural or artificial elements depending on the economic development of the area represented by the frames.

Marking points are much more difficult to locate by correlation techniques so their manual scoring is commonly done. Markings at the ends of the photogrammetric strips, which are common on the adjacent band, will be scored on both lanes at the same time to eliminate possible erroneous punctuation. All elements of the interior and exterior orientation will be exported in order to achieve the actual compensation.

### 2.3 Compensation of measurements

Aero-triangulation compensation was performed with AeroSys-AT v7.2 software. The control panel can be seen in Figure 5. As an example, the photogrammetric tape number 12, and the frame block formed by bands 8 and 9 were taken.

Point ID	Items		Weights			Deltas			
	Point Type	Wmax	Sx	Sy	Sz	Dx	Dy	Dz	Vx
44	HVpt	1.38	0.1	0.1	0.1	-0.040	-0.132	0.050	0.040
50	HVpt	0.97	0.1	0.1	0.1	-0.076	-0.039	0.049	0.076
43	HVpt	1.04	0.1	0.1	0.1	0.094	0.020	-0.019	-0.094
49	HVpt	0.66	0.1	0.1	0.1	0.043	-0.064	-0.023	-0.043
45	HVpt	3.02	0.1	0.1	0.1	0.016	0.248	0.020	-0.016
51	HVpt	2.17	0.1	0.1	0.1	-0.053	0.180	0.010	0.053
46	HVpt	1.66	0.1	0.1	0.1	-0.012	-0.018	-0.096	0.011
48	HVpt	2.18	0.1	0.1	0.1	0.028	-0.196	0.009	-0.028

Fig. 5. Evaluation of residual landmark errors on bands 8-9.

As can be seen in Figure 6, dimension points extracted from the DTM point set were used to improve accuracy.

Landmark ID	Symbol	X	Y	Z	dx	dy	dz	dx²	dy²	dz²
121	▲ Hsp	162	01	01	0.30	0.01	0.00	0.09	0.00	0.00
125	▲ Hsp	825	01	01	0.04	0.00	0.00	0.00	0.00	0.00
1212/245	▲ Hsp	855	01	01	0.01	0.00	0.00	0.00	0.00	0.00
122	▲ Hsp	850	01	01	0.00	0.00	0.00	0.00	0.00	0.00
306	▲ Hsp	245	01	01	0.03	0.02	0.00	0.00	0.00	0.00
309	▲ Hsp	125	01	01	0.01	0.04	0.00	0.00	0.00	0.00
182/224	▲ Hsp	841	01	01	0.03	0.03	0.00	0.00	0.00	0.00
1812/241	▲ Hsp	828	01	01	0.01	0.04	0.00	0.00	0.00	0.00
240	▲ Hsp	218	01	01	0.04	0.00	0.00	0.00	0.00	0.00
302	▲ Hsp	884	01	01	0.07	0.00	0.00	0.00	0.00	0.00
303	▲ Hsp	790	01	01	0.07	0.00	0.00	0.00	0.00	0.00
182/224	▲ Hsp	822	01	01	0.03	0.00	0.00	0.00	0.00	0.00
182/224	▲ Hsp	184	01	01	0.01	0.04	0.00	0.00	0.00	0.00
128	▲ Hsp	837	01	01	0.04	0.00	0.00	0.00	0.00	0.00
182/224	▲ Hsp	150	01	01	0.04	0.00	0.00	0.00	0.00	0.00
125	▲ Hsp	849	01	01	0.04	0.00	0.00	0.00	0.00	0.00
18	▲ Hsp	894	01	01	0.09	0.00	0.00	0.00	0.00	0.00
18	▲ Hsp	852	01	01	0.04	0.00	0.00	0.00	0.00	0.00
124	▲ Hsp	111	01	01	0.09	0.00	0.00	0.00	0.00	0.00
304	▲ Hsp	865	01	01	0.00	0.00	0.00	0.00	0.00	0.00
308	▲ Hsp	841	01	01	0.07	0.00	0.00	0.00	0.00	0.00
122	▲ Hsp	810	01	01	0.00	0.00	0.00	0.00	0.00	0.00
306	▲ Hsp	127	01	01	0.07	0.00	0.00	0.00	0.00	0.00
307	▲ Hsp	869	01	01	0.05	0.03	0.00	0.00	0.00	0.00
121	▲ Hsp	174	01	01	0.05	0.00	0.00	0.00	0.00	0.00
182/224	▲ Hsp	141	01	01	0.04	0.00	0.00	0.00	0.00	0.00
18	▲ Hsp	148	01	01	0.03	0.00	0.00	0.00	0.00	0.00
127	▲ Hsp	140	01	01	0.02	0.00	0.00	0.00	0.00	0.00
308	▲ Hsp	846	01	01	0.03	0.00	0.00	0.00	0.00	0.00
182/224	▲ Hsp	124	01	01	0.04	0.00	0.00	0.00	0.00	0.00
18	▲ Hsp	277	01	01	0.04	0.00	0.00	0.00	0.00	0.00
181	▲ Hsp	881	01	01	0.01	0.00	0.00	0.00	0.00	0.00
18	▲ Hsp	270	01	01	0.02	0.00	0.00	0.00	0.00	0.00
182	● Disabled	80	01	01	0.0	0.0	0.0	0.0	0.0	0.0

Fig. 6. Evaluation of residual landmark errors on the band 12.

### 3 Photogrammetric restitution and editing of plans

For the extraction of the topographic information necessary for the elaboration of the topographic situation plan at a scale of 1: 1000, the photogrammetric stereo restitution method was used.

The topographic details were extracted in separate layers in 3D mode and will then be edited to add conventional 2D mode signs.

Extracted: railways, roads, hydrography, constructions, land use category boundaries, forests, landslides, contours, elevation points and any other representative detail for the 1: 1000 scale (Figures 7 - 10).

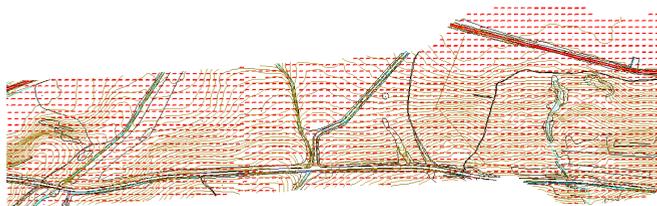


Fig. 7. Situation plan scale 1: 1000 - Lugoj Deva area - Lot1.

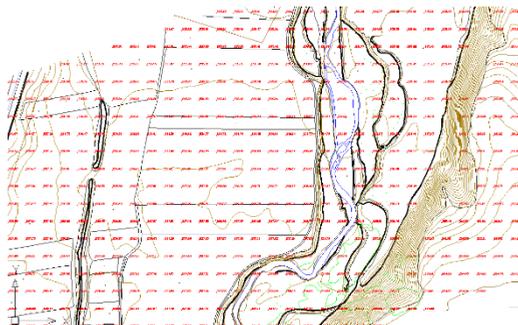
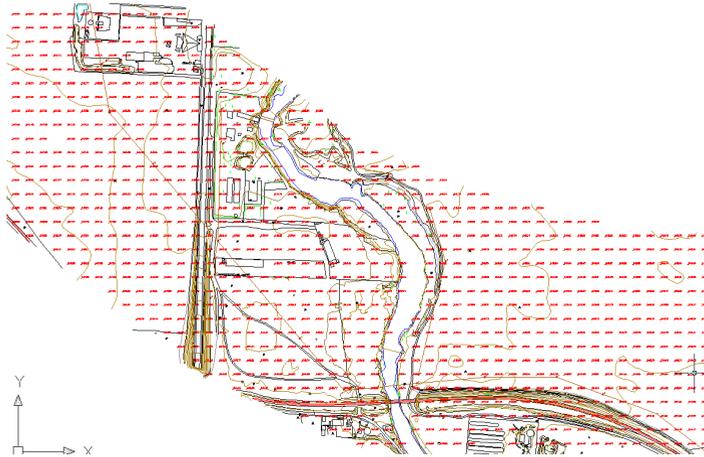
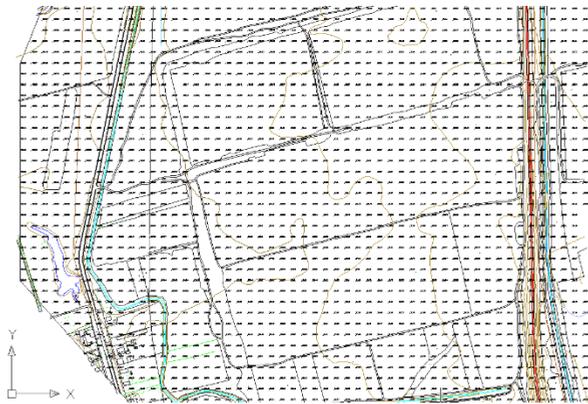


Fig. 8. Situation plan scale 1: 1000 - Orastie Sibiu area - Lot1.

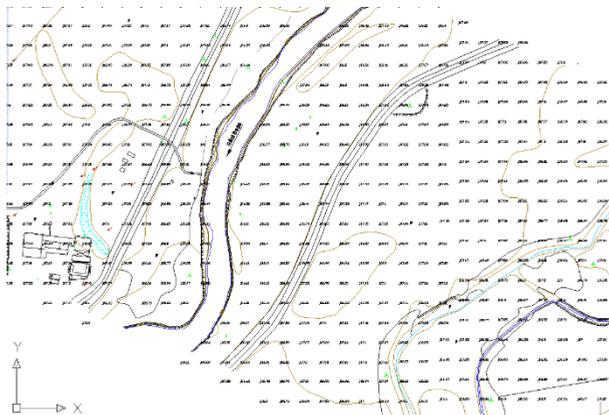


**Fig. 9.** Situation plan scale 1: 1000 - Orastie Sibiu area – Lot2.

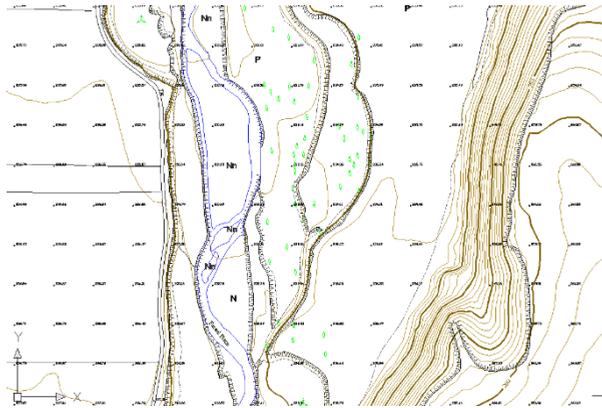


**Fig. 10.** Situation plan scale 1: 1000 - Link Road area.

The topographic plan was then edited using the atlas of conventional signs in force for the 1: 1000 scales (Figures 11 - 14). The legend used is in accordance with the atlas of conventional signs for the 1: 1000 scales.



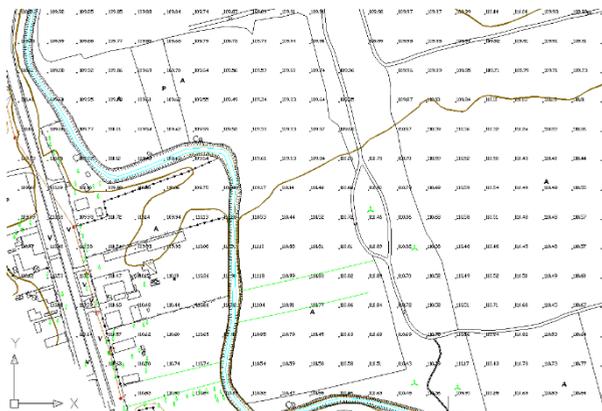
**Fig. 11.** Situation plan with conventional signs scale 1: 1000 Lugoj Deva area - Lot1.



**Fig. 12.** Situation plan with conventional signs scale 1: 1000 Orastie Sibiu - Lot1 area.



**Fig. 13.** Situation plan with conventional signs scale 1: 1000 Orastie Sibiu - Lot2 area.



**Fig. 14.** Situation plan with conventional signs scale 1: 1000 Link Road area.

## 4 Conclusion

The digital terrain model (DTM) is a numerical representation of the terrain surface  $z = f(x, y)$  but obviously an approximate representation, because the terrain has a discontinuous

shape, but is approximated by a continuous function. Even if a "spline" function is used that involves different forms of the function in different areas, their connection is made on the basis of continuity (for example, common tangent plane). The accuracy of the digital model of the land also depends on the type of land (mountainous, hill or plain area) and the topography of the area (village, forest, agricultural culture, etc.).

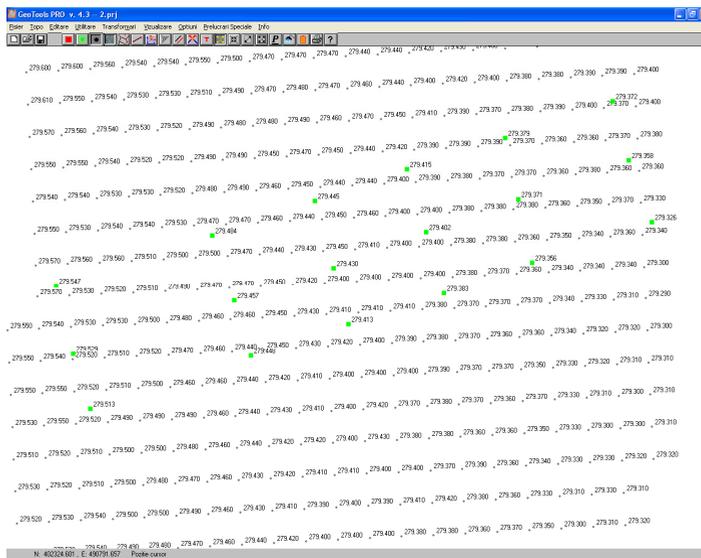
The LIDAR was used to make the DTM, which was used integrated with a digital photogrammetric camera. Similar to a topographic map, DTM represents the terrain at a certain scale or at a certain resolution. For the design of a communication path, a detailed DTM is needed, which reproduces as accurately as possible the surface of the land, so the grid nodes must be as dense as possible. In the case of this paper, a grid of points with a density of 1 point / 1 meter was made.

The verification of the accuracy of the DTM is based on a sufficient number of checkpoints measured in the field, evenly distributed throughout the area of interest. The differences on the three coordinates must be less than a certain required accuracy (eg.: for the 1: 1000 scale the accuracy on the dimension is  $\pm 0.2$  m). These check areas can be seen in Figure 15.



**Fig. 15.** Distribution of DTM verification areas obtained through LIDAR.

After performing the field level measurements on the 10 calibration zones, they overlapped with the points obtained by LIDAR technology. For this, the GeoTools v4.3 software, developed within the company, was used. The differences obtained can be seen in Fig. 16, where the points measured in the field are symbolized by green squares. For example, verification zone 2 was taken, which corresponds to polygon 33 in the DTM.



**Fig. 16.** Differences between DTM and points measured in the field.

It can be seen that the differences are of the order of centimetres, which gives us a model of the terrain of a precision superior to the requirements of the scale 1: 1000

This calibration and verification procedure was applied along the entire motorway route. To ensure an accuracy of this order of magnitude and topography, from the numerical model with the 1m grid were extracted points to the 20m grid using the GeoTools program through its own selection algorithm and not interpolation, thus completely eliminating any possible grid interpolation error.

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