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ANALYSIS OF COMPILATION TECHNOLOGY OF DIGITAL TERRAIN MODEL BASED ON SATELLITE, TACHEOMETRIC AND PHOTOGRAMETRIC DATA

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K e y w o r d s: Digital Terrain Model, GPS, RTK method.

A b s t r a c t

One of the most important, and at the same time, the most difficult task undertaken in complex process of generation geographic information system is generation of Digital Terrain Model. DTM is primary infromation layer used by systems which depict phenomena in qualitative way. It is also basic element in spatial structure of these systems. In literature there is a lot information concern obtaining terrain data to construct DTM by using photogrammetric and classical methods, but there is almost no information about using satellite methods in such purpose. In this article analysis of compilation technology of DTM generation based on data obtained due to various survey methods, including satellite one, are presented.

ANALIZA TECHNOLOGII OPRACOWANIA NUMERYCZNEGO MODELU TERENU NA PODSTAWIE DANYCH SATELITARNYCH, TACHIMETRYCZNYCH I FOTOGRAMETRYCZNYCH

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S ł o w a k l u c z o w e: Numeryczny model terenu, GPS, metoda RTK.

A b s t r a k t

Jednym z najważniejszych, a zarazem najtrudniejszych zadań, jakie są podejmowane w złożonym procesie konstruowania systemów informacji przestrzennej, jest tworzenie numerycznego modelu terenu. NMT jest podstawową warstwą informacyjną wykorzystywaną przez systemy opisujące zjawiska wartościowo i stanowi dla nich podstawę organizacji przestrzennej. W literaturze przedmiotu znajdziemy wiele informacji dotyczących pozyskiwania danych terenowych do budowy NMT metodami fotogrametrycznymi i klasycznymi, mało jest natomiast informacji o wykorzystaniu do tego celu metod satelitarnych. W artykule przedstawiono analizę technologii powstania NMT z wykorzystaniem danych z różnych metod pomiarowych, w tym również metody satelitarnej.

Introduction

Digital terrain model can be define as the collection of the points and approximate surfaces which are necessary to define relief features and to enable to determine any point of this terrain surface with given accuracy. At traditional maps information about relief features in form of contours was addition to primary map content. Nowadays DTM is stand-alone product with wide spectrum of applications. Usually it is operating as one of the layers of Geographic Information System. Co-operating with others layers it is used to conduct complex analyses in selected area.

Given area with its land development and traffic intensity is basic element significantly influence road and highway projects. Digital terrain descriptions are integral part of road and highway geometric design system. Using DTM one has following advantages:
– enables to gather terrain data in acceptable form to processing and storing,
– enables to show existing or design surface in almost any form:
  a) traditional, like contour scheme, profiles and sections,
  b) pictoral view, such as grid model.
– enables to conduct earth mass calculation.

Naturally, using DTM created some problems, the most important ones are cost- and time-consuming process of gathering data to creation DTM.

Elevation data to create DTM can be obtained by means of:
– direct measurement method (tacheometry or GPS survey),
– cartographic method (processing of existing analog maps),
– photogrametric method (processing of aerial photos or satellite images)
– aerial laser scanning method
– radar interferometry method.

Experiments description

In order to gather necessary data for creation digital terrain model surveys were conducted by following methods:
– direct GPS RTK/OTF survey,
– direct tacheometric survey,
– photogrammetric method.

Direct satellite survey

First survey was the direct satellite measurement. The terrain survey was done using a quad type vehicle (Fig. 1) on which necessary equipment for field data collection was installed. The survey equipment consisted of two precise geodesic receivers Ashtech, two navigation receivers Thales Mobile Mapper with post-processing option, GPS anntenas: geodesic and navigation and the GPRS terminal. There was also, typical for RTK survey, anntena (L1, L2) on frame construction and receiver Thales Mobile Mapper (PAJĄK 2008).

Fig. 1. The vehicle with necessary equipment for field data collection

For precise navigation survey profiles were needed. These profiles were designet on MicroMap and subsequently were converted to receiver Thales Mobile Mapper. It enabled to keep sustain vehicle in correct course during data collection (Fig. 2).

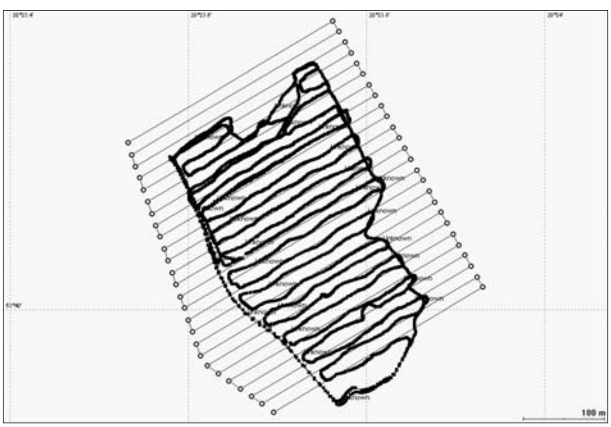

Fig. 2. Designed survey profiles in MikroMap and paths of actual navigation along them

Using real-time method during survey, coordinate were obtained in real time, corrections were transmitted using GPRS technology. They were also took into account in real time during registration to mobile receiver. Raw data were also registered and used in calculation in post-processing mode.

In RTK survey corrections transmmitted by GPRS were used what resulted in high accuracy. Mean errors of coordinate *X, Y, H* for the whole survey amounted eventually to:

$m_X = 0.096$ m, $m_Y = 0.064$ m, $m_H = 0.198$ m (PAJĄK et al. 2006).

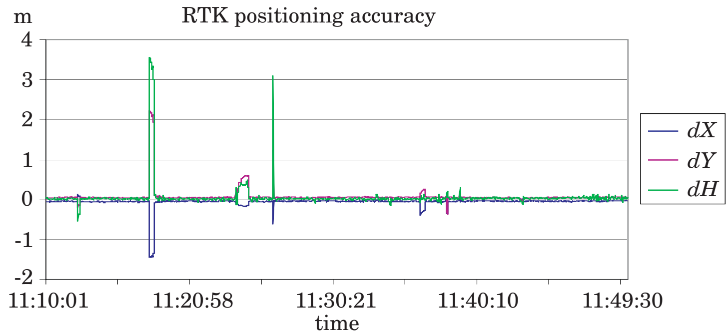

Fig. 3. Accuracy of coordinate by RTK method

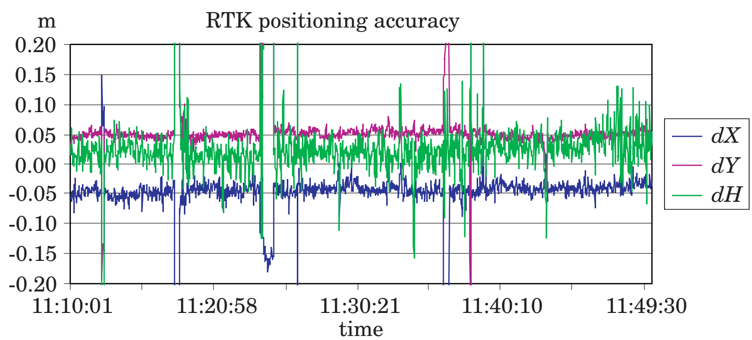

Fig. 4. Accuracy of coordinate by RTK method (zoomed)

Obtained results enabled to generate digital terrain model.

Tacheometric direct survey

During direct tacheometric survey first stage of task was static GPS measurement at three points because of the lack of national network. Obtained coordinate were used in following tacheometric calculation in Winkalk. One point was established as the station, with electronic tacheometer Leica, and two others as reference points. Distance and elevation measurements between station and reference points were taken for control. Measured distance was congruent with distance calculated from coordinate, angular discrepancy was only 0g,0010, and elevation difference was only 4 mm. After such orientation of the instrument and its control terrain point measurment began. Obtained data were used to generate digital terrain model (PAJĄK 2008).

Photogrammetric measurements

Photogrammetric method consisted of photogrammetric processing of aerial photos. In photogrammetric measurement digital photogrammetric station were used. All measurements were manual and included various point and form lines which depicted relief features as:
– scattered point in regular grid,
– form lines (brow, water-course),
– breaklines (banks, precipices),
– extreme points (summits, bottoms).

Measurements of photogrammetric model took place at Okręgowe Przedsiębiorstwo Geodezyjno-Kartograficzne in Olsztyn. Area study was located in one stereogram. Measurements were done with digital photogrammetric station Intergraph using:
– aerial photos, colour negative form 1995, scale 1:26 000,
– scanned images of aerial photos in scale 1:26 000, pixel = 30 μm, 24 bpp, format Intergraph TIFF, then images were converted to Intergraph TIFF with compression JPEG, quotient Q = 10,
– photogrammetric network consisted of control points, whose coordinate were estimated by means of GPS survey.

High accuracy of correlated measurements of fiducial coordinates in digital image was guaranteed. Sigma error did not exceed 8 μm. Digital terrain model was generated manually. Coordinates were collected for over 800 points in area of about 5 ha, with spatial distribution in regular grid 10 m – 10 m. form lines, breaklines-banks, extreme points were also measured (PAJĄK 2008).

Statistical analyses

These analyses are based on examination of surfaces GRID created by using data obtained with three various methods: tacheometric, satellites and photogrammetric. For surface interpolation kriging method was used. In order to test difference between GRID surfaces, size for grid was selected as 4 m × 4 m and 8 m × 8 m,. Neither breaklines nor extreme lines were taken into account. Analyses included also TIN surfaces, which was presented in other article.

In statistical evaluation of GRID surface following parameteres were considered:

– variance and standard deviation of GRID surface – it describes dispersion of data around arithmetic mean.

$$dH_{\text{śr}_{\text{TACH-RTK,FOT}}} = \frac{(H_{1_{\text{TACH}}} - H_{1_{\text{RTK,FOT}}}) + \ldots + (H_{n_{\text{TACH}}} - H_{n_{\text{RTK,FOT}}})}{n}$$

$$V(H) = \frac{[(dH_{1_{\text{TACH-RTK,FOT}}} - dH_{\text{śr}_{\text{TACH-RTK,FOT}}})]^2 + \ldots +}{n-1}$$

$$\frac{+ \ldots + [(dH_{n_{\text{TACH-RTK,FOT}}} - dH_{\text{śr}_{\text{TACH-RTK,FOT}}})]^2}{n-1}$$

$$\delta(H) = \sqrt{V(H)}$$

where:

$dH_{1 \ldots n_{\text{TACH-RTK,FOT}}} = dH_{1 \ldots n_{\text{TACH}}} - dH_{1 \ldots n_{\text{RTK,FOT}}}$ – values of successive differences between elevations in GRID surfaces based on data from satellite (photogrammetric) survey and tacheometric one.

$dH_{\text{śr}}$ – mean value of difference in elevation of GRID surfaces based on data from satellite (photogrammetric) survey and tacheometric one.

n – number of points,

– RMS- Root Mean Square.

$$\text{RMS} = \sqrt{\frac{(dH_{1_{\text{TACH-RTK,FOT}}})^2 + \ldots + (dH_{n_{\text{TACH-RTK,FOT}}})^2}{n}}$$

where:

$dH_{1 \ldots n_{\text{TACH-RTK,FOT}}} = dH_{1 \ldots n_{\text{TACH}}} - dH_{1 \ldots n_{\text{RTK,FOT}}}$ – values of successive differences between elevations in GRID surfaces based on data from satellite (photogrammetric) survey and tacheometric one.

n – number of points.

Analyses of GRID surfaces based on data used for DTM generation, obtained by means of three survey methods

Using three survey methods terrain data were collected, and their spatial distributions are presented in Figure 5.

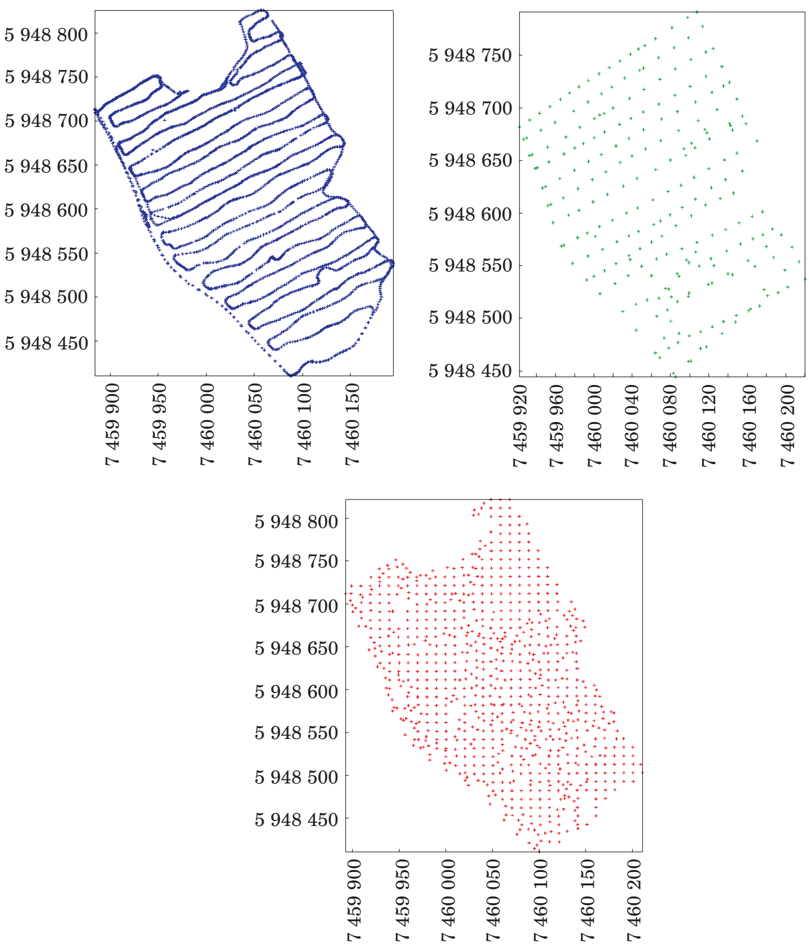

Fig. 5. Spatial distribution of data obtained from satellite RTK, tacheometric and photogrammetric methods

After superimposition of data obtained from three survey methods, overlap area was determined and became the object of subsequent analyses (Fig. 6) (on account of small size of overlap area the area study was limited).

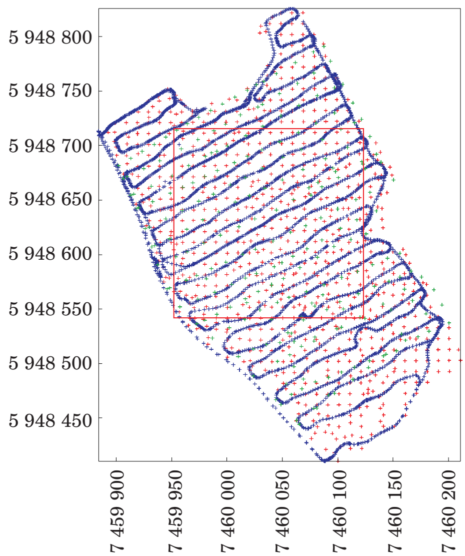

Fig. 6. Spatial distribution of superimposed data obtained from three survey methods and determination of overlap area for subseqent analyses

Obtained data enables to interpolate GRID with step size 4 m × 4 m and 8 m × 8 m.

Analysis included calculation of elevation differences in common points of GRID surfaces constructed with data from direct tacheometric and direct satellite surveys and also calculation of variance, standard deviation, RMS and minimal, maximal and mean difference between elevations for these surfaces.

– For search radius of 60m, and GRID with steps 4 m × 4 m and 8 m × 8 m mentioned values amounted to:

Table 1

Analyses of GRID surfaces

Specification	$GRID_{TACH\text{-}RTK}$ (4 m × 4 m)	$GRID_{TACH\text{-}RTK}$ (8 m × 8 m)
Variance (m)	0.046	0.039
Standard deviation [m]	0.215	0.198
RMS [m]	0.219	0.200
Min [m]	-0.507	-0.395
Mean [m]	0.038	0.031
Max. [m]	2.096	1.376

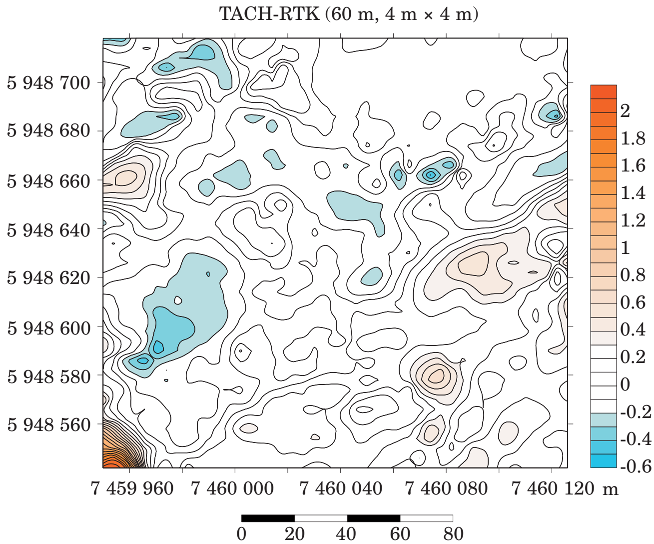

Fig. 7. Map of distribution of elevation differences on surface GRID 4 m × 4 m

Analysing results of calculation, analyses and comparison in the table it can be observed that for differential surface GRIDRTK-TACH 4 m × 4 m with searching radius of 60 m RMS was 0.219 m, standard deviation 0.215 m, mean difference of elevation for this surface is 0.038 m. For differential surface GRIDRTK-TACH 8 m × 8 m with the same searching radius mentioned parameters amounted 0.200 m, 0.198 m, 0.031, respectively. Distribution of differences in elevation for differential surface GRIDTACH-RTK 4 m × 4 m is presented in Figure 7.

In Figure 8 distribution of elevation differences in differential surface GRIDTACH-RTK, 8 m × 8 m, resulted from comparison surfaces GRID created with data from direct tacheometric and direct satellite surveys.

After analysing data obtained from two survey methods, for GRID 4 m × 4 m and GRID 8 m × 8 m digital models with searching radius of 60 m were generated.

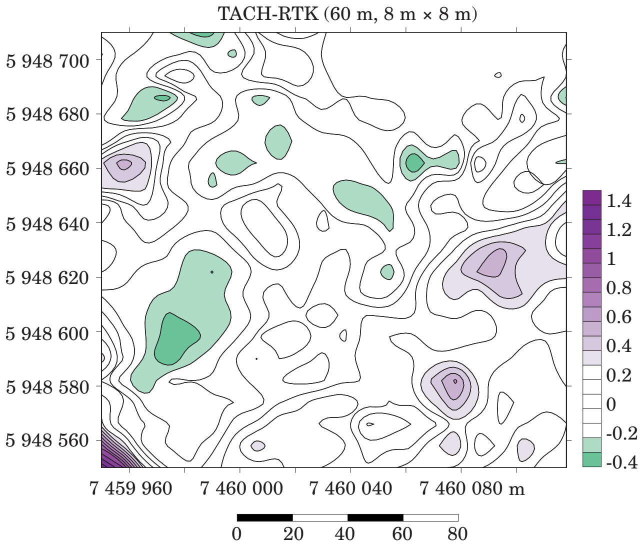

Fig. 8. Maps of distribution of elevation differences on surface GRID 8 m × 8 m

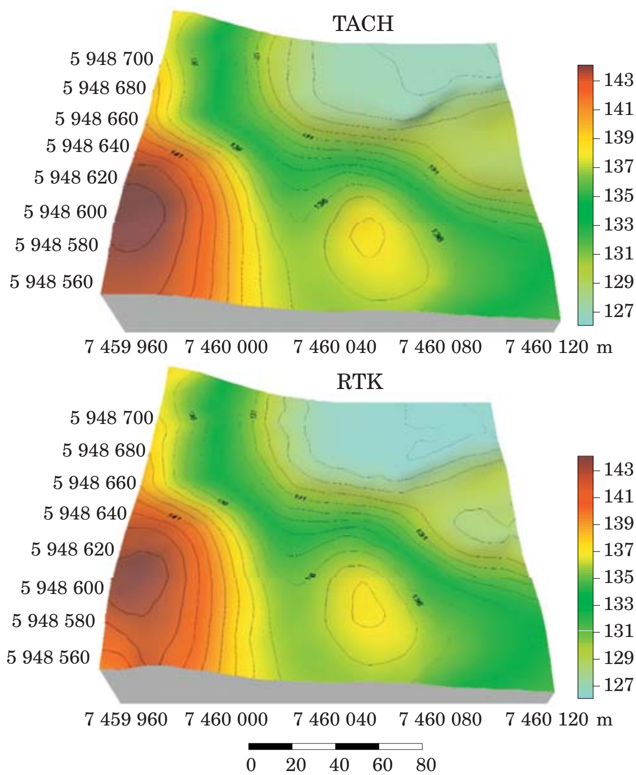

Fig. 9. DTM with contours, grid 4 m × 4 m, searching radius 60 m

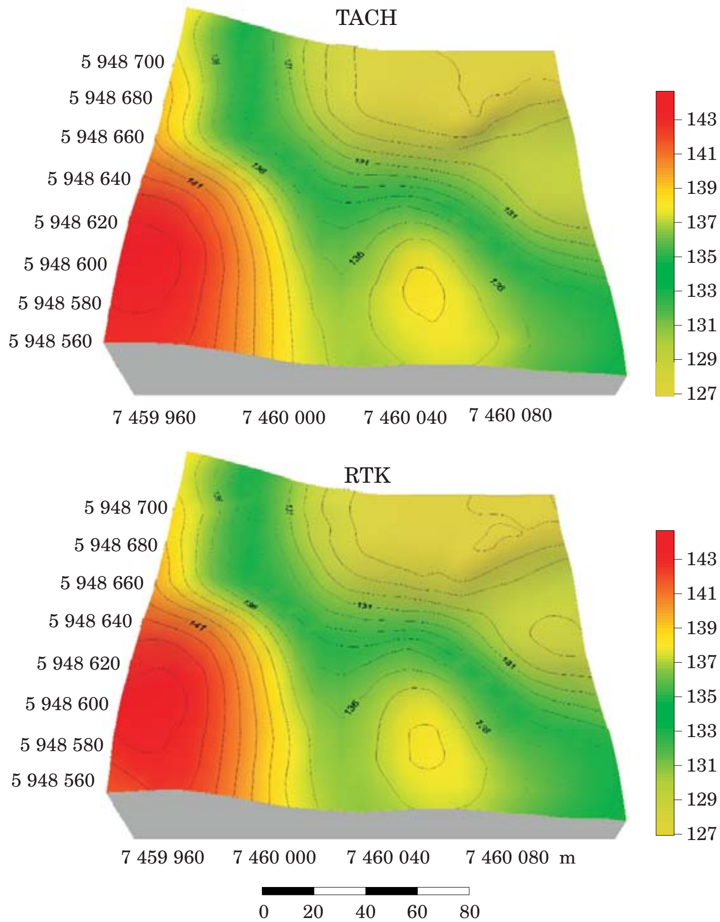

Fig. 10. DTM with contours, grid 8 m × 8 m, searching radius 60 m

Analysing presentations in Fig. 9 and 10, showing digital model generated from data collected by means of direct tacheometric and satellite surveys. It is seen that there is neither disturbances in elevations nor in spatial characterics of study area. Interpretation of contours presented in figure allow us to conclude that there is no significant difference between models based on direct tacheometric and direct satellite surveys.

Second analysis included calculation of elevation differences at common points of GRID surfaces generated from data gathered by using direct tacheometric survey and photogrammetic method. Variance, standard devation, RMS, minimal, maximal and mean difference between elevation for these surfaces were also objects of interest.

– For search radius of 60 m, and GRID with steps 4 m × 4 m and 8 m × 8 m mentioned values amounted to:

Table 2

Analyses of GRID surfaces

Specification	GRIDTACH-RTK (4 m × 4 m)	GRIDTACH-RTK (8 m × 8 m)
Variance (m)	0.090	0.086
Standard deviation [m]	0.301	0.292
RMS [m]	0.430	0.426
Min [m]	-0.559	-0.559
Mean [m]	0.307	0.311
Max. [m]	2.422	1.908

Like in previous analysis, and with the same condition about searching radius for differential surface GRIDRTK-TACH 4 m × 4 m RMS was 0.403 m, standard deviation 0.301 m. Mean difference of elevation for surface GRID-TACH-FOT 4 m × 4 m was 0.307 m. For differential surface GRIDRTK-FOT 8 m × 8 m mentioned parameters were 0.426 m, 0.292 m, 0.311, respectively. Distribution of differences in elevation for differential surface GRIDTACH-FOT 4 m × 4 m is presented in Figure 11.

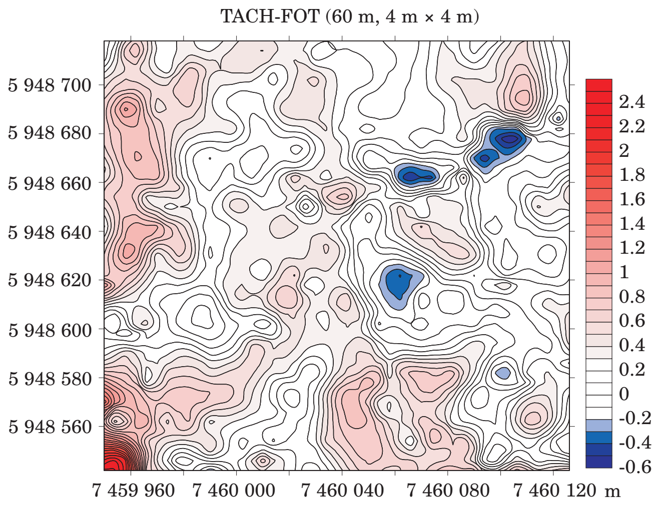

Fig. 11. Map of distribution of elevation differences on surface GRID 4 m × 4 m

Distribution of differences in elevation for differential surface GRIDTACH-FOT 8 m × 8 m is presented in Figure12.

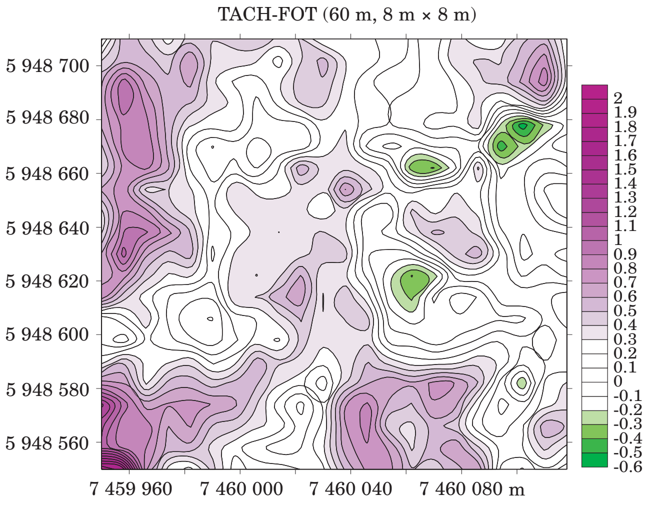

Fig. 12. Map of distribution of elevation differences on surface GRID 8 m × 8 m

After analysing data obtained from two survey methods, for GRID 4 m × 4 m and GRID 8 m × 8 m digital models with searching radius of 60 m were generated (Fig. 13, 14).

Analysing presentations in Fig. 13 and 14, showing digital model generated from data collected by means of direct tacheometric and photogrammetric methods there is neither disturbances in elevations nor in spatial characterics of study area. Interpretation of contours presented in figure allow us to conclude that there are places on model, generated by using photogrammetric methods, where contours in comparison to theirs respective location on model based on direct tacheometric survey diverged (PAJĄK 2008).

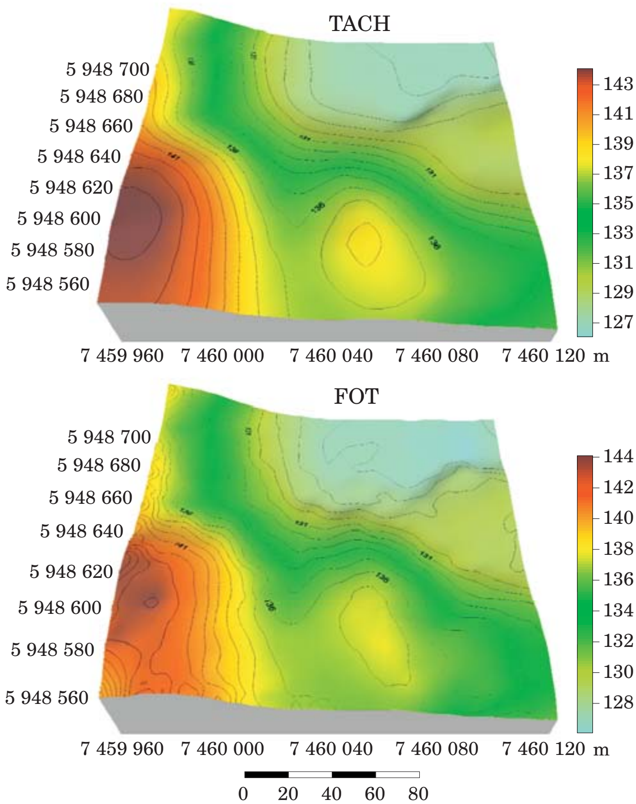

Fig. 13. DTM with contours, grid 4 m × 4 m, searching radius 60 m

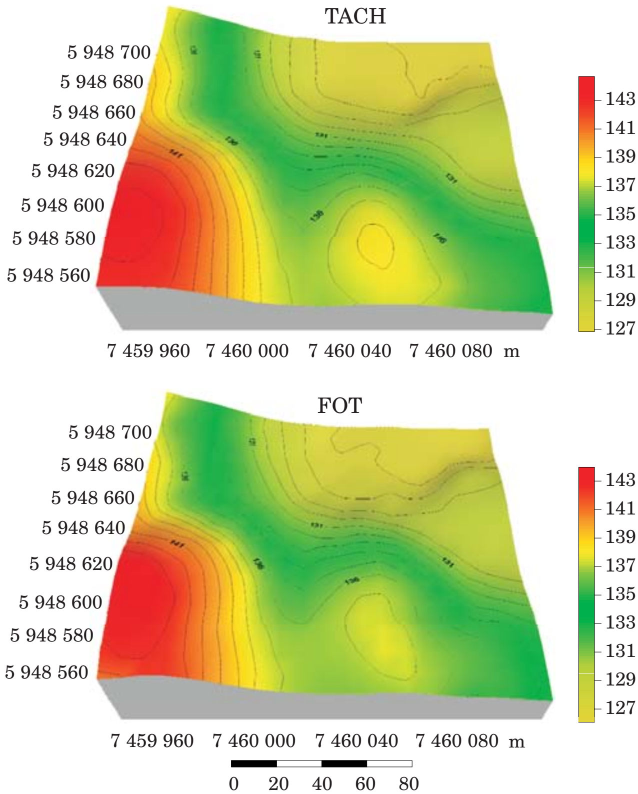

Fig. 14. DTM with contours, grid 8 m × 8 m, seeking/searching radius 60 m

Conclusions

Direct satellite surveys RTK GPS/OTF enabled to collect a lot of measurement points in relatively short time, in cheap, fast and safe way.

In comparison to tacheometric method, mean difference in elevation is 3 cm, and standard deviation 20 cm for surfaces created as GRID.

GPS method for measurement of terrain data used for DTM generation is fast method with high accuracy. However, despite of high class equipment used in experiments it can be stated that there is a significant influence of any changes in satelite configuration on survey accuracy.

There is one leading factor arguing for satellite technology, namely efficiency seen as reducing time of acquisition of accurate data required to DTM creation. The evidence of reducing time-consuming aspect of gathering data is 90 minutes when area of 5 ha were measured, and there was only one person in vehicle. Others methods needed much more time.

Analyses which took into account various models, confirmed that model generated from data obtainted by satellite methods gives better result in comparison to photogrammetric method.

The final results of the following study is function describing.

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