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INTERPOLATION GRID FOR LOCAL AREA OF IASI CITY

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Abstract. Definitive transition to GNSS technology of achieving geodetic networks for cadastre implementation in cities and municipalities, enforce establishing a unique way of linking between current measurements and existing geodetic data, with a sufficient accuracy proper to urban cadastre standards. Regarding city of Iasi, is presented a different method of transformation which consist in an interpolation grid for heights system. The Romanian national height system is „Black Sea-1975" normal heights system. Founded in 1945 by Molodenski, this system uses the quasigeoid as reference surface, being in relation with the ellipsoid through the height anomalies sizes in each point. The unitary transformation between the ETRS-89 ellipsoidal height system and the normal one, at national level is provided through the „TransdatRo" program developed by NACLR (National Agency for Cadastre and Land Registration).

Introduction

The adoption in 2000 of the ITRS89 (International Terrestrial Reference System), was probably one of the most important achievements of geodesy of all time, because it provided a tool with which users can control both the positions of the points on the surface land and how these positions over time. This is geocentric reference system and its geometrical and physical parameters are the result of observation campaigns, extensive research and analysis on more than 30 years.

Regarding systems altitudes, the situation is unusual, being used practically all altitudes systems designed throughout history geodesy.

The trend of using satellite positioning systems and global satellite mapping systems may introduce serious practical difficulties if the results must be reported to the old maps or digital data. Consequently, it not only requires the data transfer between geodetic reference systems but also between cartographic projection systems referred to different reference systems.

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Regarding Iaşi city, it has been designed and built a geodetic network through GNSS technology, consisting of a total of 84 points evenly distributed across the entire city. They have been designed under the form of a support base for the development of further closed traverses and they are located two by two at close distances up to 200 meters. In 2005, the network was determined using the WGS-84 system. In 2010, some of the basic network points have been determined again in the ETRS-89 system, which became official in Romania since 2009, so that all network coordinates were transformed into the European datum under the centimeter precision (Chirila, C., Mihalache, Raluca Maria, 2011). Through this transformation, a data set containing the ellipsoidal heights of the network points known in ETRS-89 system was obtained. Due to the network relatively small surface of about 600 square kilometers, the initial precision for the ellipsoidal heights determination falls, generally, in the range of 2-3 cm (Chirila, C., Manuta, A., 2006).

After the closed traverses execution, a precise levelling network was design, containing horizontal network points and, implicitly, those of the geospatial network from Iasi city. The measurements have had on basic the class one landmarks from the national levelling network there for after geodetic processing, normal heights were obtained in "Black Sea-1975" national system. Following measurements campaigns have resulted a number of 37 polygons, which totalled 145 Km, statistics highlighting a superior precision, in the range of few millimeters, obtained than GNSS technology. (Salceanu, G., 2009).

Given the existence of two data sets for a significant number of points, it is possible to apply a transformation model for the differences of the ellipsoidal heights, obtained with a millimeters precision on short distance, by GNSS technology, in normal heights system required in current practice. Through these, normal heights for the new points are resulted with a centimeters precision, avoiding the long-time execution need it for this kind of works.

Methods and algorithm

1.Theoretical review

A consistent technique for converting data from one datum to another shall maintain integrity and topology of existing data set and to ensure identical processing results regardless of who performs this transformation.

A model for transforming coordinates from one datum to another, adopted as an international standard, it must meet four criteria:

- Simplicity- to facilitate understanding and adoption by users;
- Efficiency-to minimize the time and computational requirements;
- Uniqueness-to ensure that a single solution;

• Rigor-to provide the best possible outcome of transformation.

Making a complex model transformation based on interpolation regular network (grid) is a convenient and widely accepted practice that meets the first three criteria.

Original method implemented in modelling surface for the heights transformation is based on polynomial functions. For monitoring precision variations it has been developed three different algorithms for the transformation by polynomial degrees, making the correlation between horizontal positioning points and height anomalies (Bofu, C., Chirila, C. , 2007):

- $\zeta = a_{00} + a_{10}\,x + a_{01}\,y$ (1st degree)
- $\zeta = b_{00} + (b_{10}\,x + b_{01}\,y) + (b_{20}\,x^2 + b_{11}\,xy + b_{02}\,y^2) + (b_{30}\,x^3 + b_{21}\,x^2y + b_{12}\,xy^2 + b_{03}y^3)$ (3rd degree)
- $\zeta = c_{00} + (c_{10}x + c_{01}y) + (c_{20}x^2 + c_{11}xy + c_{02}y^2) + (c_{30}x^3 + c_{21}x^2y + c_{12}xy^2 + c_{03}y^3) + (c_{40}x^4 + c_{31}x^3y + c_{22}x^2y^2 + c_{13}xy^3 + c_{04}y^4) + (c_{50}x^5 + c_{41}x^4y + c_{32}x^3y^2 + c_{23}x^2y^3 + c_{14}xy^4 + c_{05}y^5) + (c_{60}x^6 + c_{51}x^5y + c_{42}x^4y^2 + c_{33}x^3y^3 + c_{24}x^2y^4 + c_{15}xy^5 + c_{06}\,y^6)$ (6th degree)

where:

- $\zeta = (H^E - H^n)$ = height anomaly in point, calculated as the difference between ellipsoidal height (H^E) and normal height (H^n);
- (x,y) = the horizontal rectangular coordinates in the national map projection (Stereographic-1970);
- a_{ij}, b_{ij}, c_{ij} = the transformation coefficients, which are determined by the adjustment.

Solving the above equations, lies to the applying the principle of least squares, based on the excess points to the minimum necessary, obtaining the unknown parameters represented by the transformation coefficients. For the precision evaluation of the results, was retained for statistical analysis, the mean square error transformation for height anomaly of a point:

$$s_0 = \sqrt{[vv]/(r-n)}$$

where **r** represent the number of common points and **n** the number of unknown parameters.

2. Algorithm

Of the 84 points of Iasi city geospatial network, only 71 points were selected in processing algorithm. These have heights determined in both systems, ellipsoidal and normal, with no errors outstanding in terms of the anomalies values.

Further was continuing a data filter through comparing height anomalies to a smooth surface, by "v4" method of Matlab software, using a grid interval of 300 m (Figure 1).

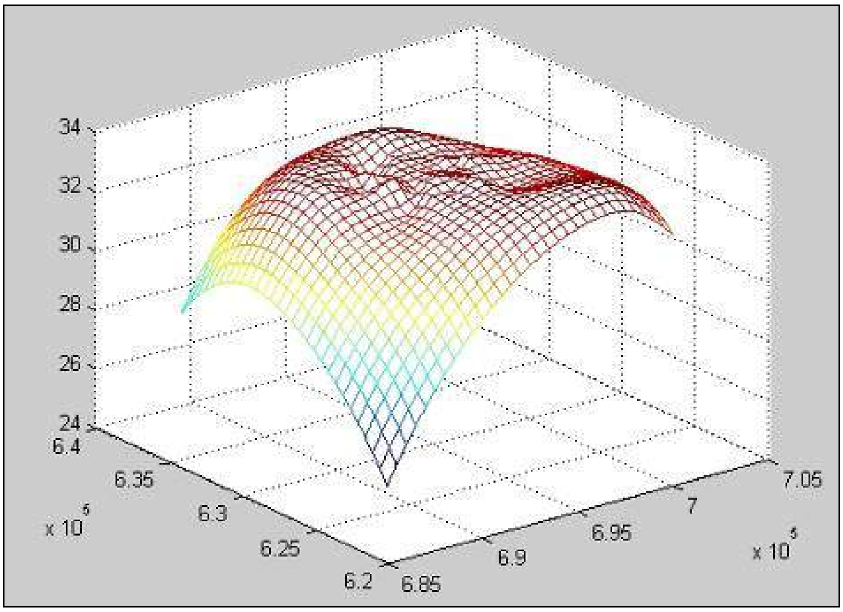

Fig. 1: Interpolated surface height anomalies by the "v4" method of Matlab software

Over 5 cm above a limit set for the differences between the known height anomalies and the ones, produced by the interpolation, have been removed from the adjustment model. Therefore, a total of 63 points were accepted according with the interpolation surface development.

Additionally, a graphics survey was conducted over the isolines generated by the height anomalies variation. It was observed the continuity of the model, without eliminating other points further processing (Dumitru, P.D. , 2011).

For other height anomalies interpolations testing were performed, in Matlab software, using several variants of spacing grid, with methods for linear interpolation, nearest neighbor, cubic and "v4" (www.mathwork.com).

3. Results and discussion

Obtained results for the three variants of polynomial interpolations are shown in **table 1**. It is noted that through the application of a polynomial function of 6th degree, the smaller mean square error is obtained with the best results for the control point. The latter was chosen on GNSS reference station site of the Hydrotechnics, Geodesy and Environmental Engineering Faculty of Iasi, with ETRS-89 geodetic coordinates and normal height determined with precision:

B = 47°09'20.19756"N; L = 27°35'55.55345"E; H^E = 89.985 m; H^n = 57.643 m

In the case of interpolation in Matlab using the four methods mentioned above, it is presented in the Table 2, standard deviation variation in height anomalies of common points for increasing the grid interval with 100m.

Table 1: Polynomial interpolation results for height anomalies

Polynomial transformation algorithm	The number of coefficients	The number of degree of freedom	Mean square error transformation s_0 (cm)	Deviation in the control point (cm)
1st degree	3	60	20.2	8.6
3rd degree	10	53	19.7	11.6
6st degree	28	35	16.1	6.6

Table 2:Statistical analysis of data set for interpolation in Matlab

Grid	The standard deviation of height anomalies in common points used in interpolation (cm)			
	Linear	Nearest neighbor	Cubic	“v4”
100 m	1.78	0.00	0.46	-
200 m	3.27	0.67	0.79	0.62
300 m	5.09	0.68	2.35	1.45
400 m	6.17	5.28	3.52	2.52

It is observed that as the grid interval increases the standard deviation also increases, so it is recommended that an interval as small, but not consume too much of computing resources (100 m - 200 m). For example, the statistics obtained at the interval grid of 200 m, in the four interpolation methods and the testing performed in the control point, are shown in Table 3.

Table 3: The results of interpolation by Matlab methods (200m)

Interpolation method	Mean deviation of transformation (cm)	Maximum value of deviation (cm)	Average deviation in absolute value from the mean (cm)	Deviation in the control point (cm)
Linear	3.27	9.04	2.24	8.7
Nearest neighbor	0.68	5.40	0.17	9.1
Cubic	0.79	3.13	0.44	7.9
“v4”	0.62	1.80	0.47	5.8

The graphic representations of surfaces thus obtained are presented in Figure 2, where the chosen grid interval is 500 meters, for better image quality.

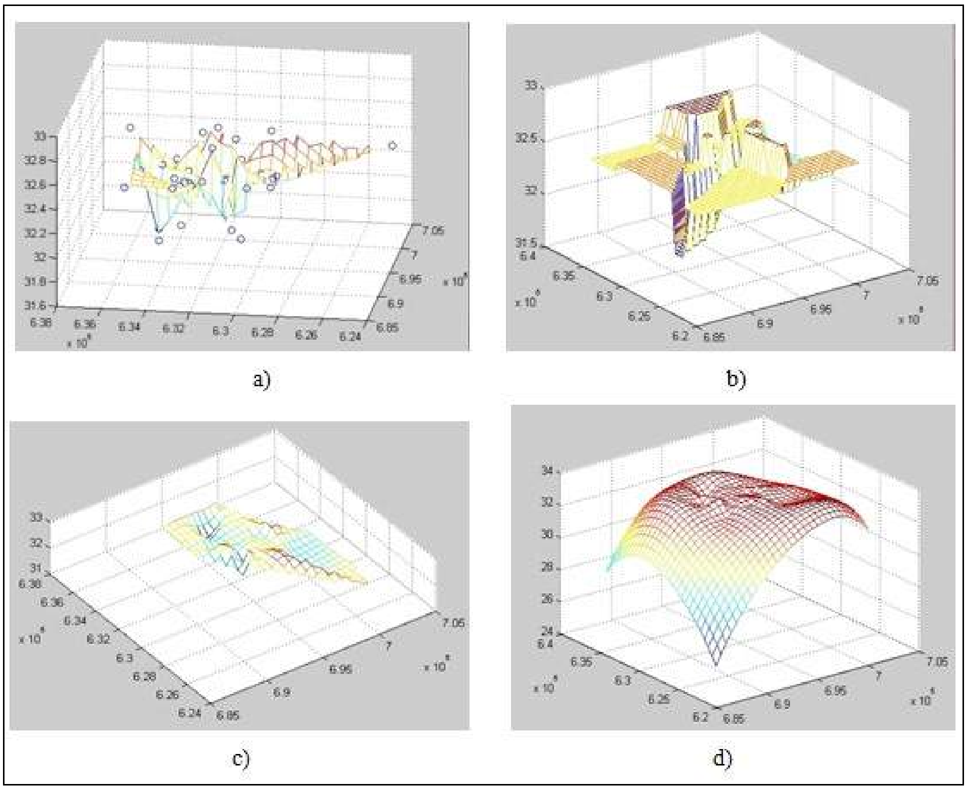

Figure 2: Interpolated surface for height anomalies by linear (a), nearest neighbor (b), cubic (c) and „v4” (d) method, for the 500 m grid interval

In Table 4 is presented statistical analysis of the data set, represented by the height anomalies in the common points, to highlight the variants of works, with improvements in relation with national TransdatRO application for the transformation of geodetic coordinates ETRS-89 in the national system (stereographic - 1970 projection and the heights system of “Black Sea – 1975”).

Table 4: Statistical analysis of the differences between height anomalies obtained from GNSS measurements and levelling, respectively by application TransdatRO

Data set	Absolute average value	Absolute maximum value	Absolute minimum value	Standard deviation in data set s_o
63 points	17.60 cm	65.56 cm	0.77 cm	23.41 cm

There is to be seen an improvement in the results, for the common points, of the interpolated surface by applying local modelling for the heights transformation, at centimeter level.

Conclusions

Determining an accurate model of quasigeoid in Romania is a current concern in the domain of geodetic surveying. Due to insufficient data in the gravimetric measurements, the model developed nationally by National Agency for Cadastre and Land Registration (TransdatRO), requires further improvements for filling with new data from measurements and tests on multiple checkpoints.

In this context, the paper addresses a practical problem of modelling by geometric methods of interpolation for small areas at the local level. The available measurements consist of two data sets resulting from local GNSS and levelling network measurements of the municipality.

The data set was analysed statistically by the correlation between horizontal positioning points and height anomalies calculated at each point. The average height anomaly is 32.247 m. The maximum value is 3.632 m, the minimum is 31.734 m and standard deviation of about 20 cm.

Data filtering was performed by a method compared to a smooth surface obtained in “v4” interpolation method of Matlab and observing graphically the isolines of the height anomalies. It must be considered that this filter does not exclude some points that could reveal anomalies variation in land elevation.

When applying the selected methods of interpolation in Matlab software, it is recommend choosing a grid interval as small, but not consume too much of computing resources. A grid interval of 100 - 200 m is sufficient for a small stretch zone. Although the standard deviation of transformation can be very good for the common points, it is necessary that testing be performed on control points. Results on the checkpoint between the four methods discussed (linear, nearest neighbor, cubic and "v4") lead to results close to each other and to higher order polynomial transformation.

Choosing a method of the set is recommended to be taken after testing a sufficient number of control points distributed uniformly across the area. Also, combining geometric model derived from GNSS and levelling measurements with European regional gravity model can provide better results in correcting height anomalies and could provide the basis for accuracy in geodetic works.

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