

DEVELOPMENT OF TRANSFORMATION PARAMETERS DATA BASE FOR MOLDPOS SERVICE

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Abstract: *Starting from 1999 a new Moldavian Reference System (MOLDREF99) based on the ETRS89 and Transversal Mercator for Moldova map projection was established. In order to provide real time position and navigation service on the territory of Republic of Moldova in 2011 GNSS Permanent Network and MOLDPOS service was developed. Taking in account that RTCM 3.1 transformation messages allows the MOLDPOS service to provide their users with all necessary data for positioning a grid transformation parameters data base from combined classical triangulation SC42 to MOLDREF99 and vice versa was developed, using a new method of grid calculation and interpolation of Helmert transformation parameters. Case study in the central part of Moldova showed centimeters level accuracy of coordinate's transformations from SC42 datum to MOLDREF99 and inverse.*

Keywords: *reference system, map projection, transformation parameters, real time positioning, coordinate transformations, grid calculation, data base.*

1. Introduction

Starting from 1999 a new Moldavian Reference System (MOLDREF99) based on the ETRS89 and Transversal Mercator for Moldova (TMM) map projection was established, however a lot of materials remain in old classical soviet 1942 system of coordinates (SC42) and needs to be georeferenced.

In 2011 on the territory of Moldova ten GNSS continuously operating stations with GPS/NAVSTAR, GLONASS and Galileo capacity receivers were installed in the frame of GNSS Permanent Network and Moldavian Positioning (MOLDPOS) Service project supported by Norwegian Government.

MOLDPOS service provides differential corrections and quasigeoid heights for determination of horizontal coordinates in MOLDREF99 reference system and normal altitudes related to the Baltic Sea height system. The next step is development of transformation parameters database in order to provide forward transformation from old classical datum SC42 to the MOLDREF99, ETRS89 related position and and vice versa for large spectrum of applications: geodetic works, cadastral works, surveying, GIS, mapping, navigation, precise agriculture, landslide monitoring, environmental research, geohazard prediction, meteorology, etc.

The aim of this work was to find suitable solution for grid calculation of transformation parameter for all territory of the country in order to increase accuracy of coordinates transformation, special on the boundary between the regions, and to provide a unique transformation parameters data base for entire territory of Republic of Moldova. The computed high precise parameters to be stored to transformation parameter database for setting up the recent world-standard of RTCM 3.1 transformation messages for the GNSS

3. Calculation algorithm

Taking in account that the old triangulation geodetic sites are given in SC42 ellipsoidal coordinates $(\varphi, \lambda, h)^{SC42}$ first step is the transformation to geocentric three-dimensional coordinates $(X, Y, Z)^{SC42}$ using well known equations:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} (N + h) \cos \varphi \cos \lambda \\ (N + h) \cos \varphi \sin \lambda \\ [N(1 - e^2) + h] \sin \varphi \end{bmatrix} \quad (1)$$

where: N - radius of curvature in the prime vertical., e – first eccentricity of ellipsoid.

Using at least three common geodetic sites with coordinates determined in both reference systems ETRS89 and SC42 the transformation parameters were calculated using the following equations of corrections:

$$\begin{pmatrix} X_1^{ETRS89} - X_1^{SC42} \\ Y_1^{ETRS89} - Y_1^{SC42} \\ Z_1^{ETRS89} - Z_1^{SC42} \\ \cdot \\ \cdot \\ X_n^{ETRS89} - X_n^{SC42} \\ Y_n^{ETRS89} - Y_n^{SC42} \\ Z_n^{ETRS89} - Z_n^{SC42} \end{pmatrix} - \begin{pmatrix} v_{X1} \\ v_{Y1} \\ v_{Z1} \\ \cdot \\ \cdot \\ v_{Xn} \\ v_{Yn} \\ v_{Zn} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & X_1^{SC42} & 0 & -Z_1^{SC42} & Y_1^{SC42} \\ 0 & 1 & 0 & Y_1^{SC42} & Z_1^{SC42} & 0 & -X_1^{SC42} \\ 0 & 0 & 1 & Z_1^{SC42} & -Y_1^{SC42} & X_1^{SC42} & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & 0 & 0 & X_n^{SC42} & 0 & -Z_n^{SC42} & Y_n^{SC42} \\ 0 & 1 & 0 & Y_n^{SC42} & Z_n^{SC42} & 0 & -X_n^{SC42} \\ 0 & 0 & 1 & Z_n^{SC42} & -Y_n^{SC42} & X_n^{SC42} & 0 \end{pmatrix} \cdot \begin{pmatrix} t_x \\ t_y \\ tz \\ m \\ \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} \quad (2)$$

Solving linear equations using least squares method, 7 Helmert transformation parameters were calculated in each 16 nodes of 9 cells of pilot zone. The geodetic sites were selected within the radius of 8.5 km from each node with at least one common site with neighbouring nodes (Fig. 2).

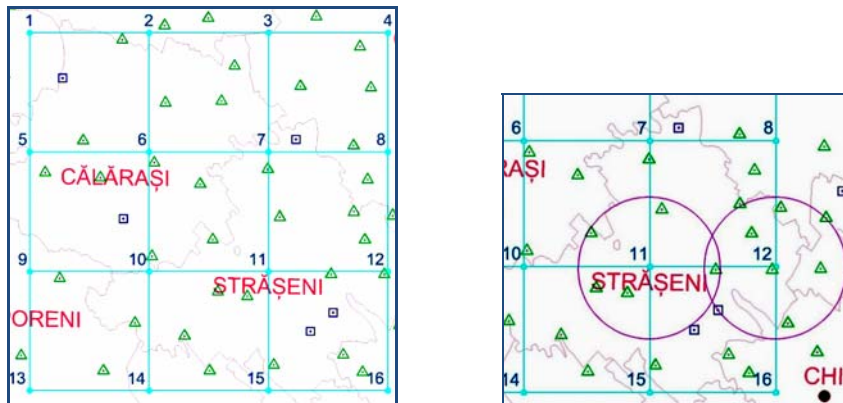


Fig. 2. Establishment of radius and cells dimension in pilot zone

As result 7 transformation parameters were calculated for each of 16 nodes in order to have for each cell 4 sets of transformation parameters (Table 1).

Table 1. Sets of transformation parameters for nodes

Nodes	t_x, m	t_y, m	t_z, m	$m, 10^{-6}$	ω_x''	ω_y''	ω_z''
1	0,534	154,934	109,718	-6,147	0,035	0,234	1,038
2	-15,482	145,496	89,535	-1,839	-0,735	-0,176	0,063
3	-4,208	153,330	105,807	-5,171	0,259	0,322	1,326
4	-7,619	151,503	100,572	-4,154	0,750	0,619	1,944
5	-10,782	148,696	95,417	-3,121	0,098	0,275	1,112
6	-7,524	151,602	99,538	-4,048	1,777	1,191	3,225
7	-3,838	152,201	103,570	-4,890	-0,112	0,169	0,850
8	-14,271	151,067	94,346	-2,792	-2,071	-0,930	-1,399
9	-12,118	148,911	92,799	-2,705	-0,719	-0,127	0,175
10	-16,532	145,730	88,279	-1,608	0,246	0,360	1,302
11	-10,972	148,905	94,971	-3,062	-0,061	0,201	0,940
12	4,354	141,733	107,611	-5,585	4,656	2,737	5,970
13	-1,477	150,207	101,949	-4,827	5,706	3,341	7,813
14	-1,872	155,348	105,255	-5,429	0,736	0,665	1,988
15	-10,326	150,512	95,542	-3,271	1,147	0,872	2,46
16	-6,179	151,547	101,766	-4,429	-0,263	0,068	0,682

To calculate transformation parameters ($t_x, t_y, t_z, m, \omega_x, \omega_y, \omega_z$) for geodetic site (x, y) within cells a bilinear interpolation methods was used as function of the distances ($\Delta x, \Delta y$) and grid dimension s respectively (Fig. 3).

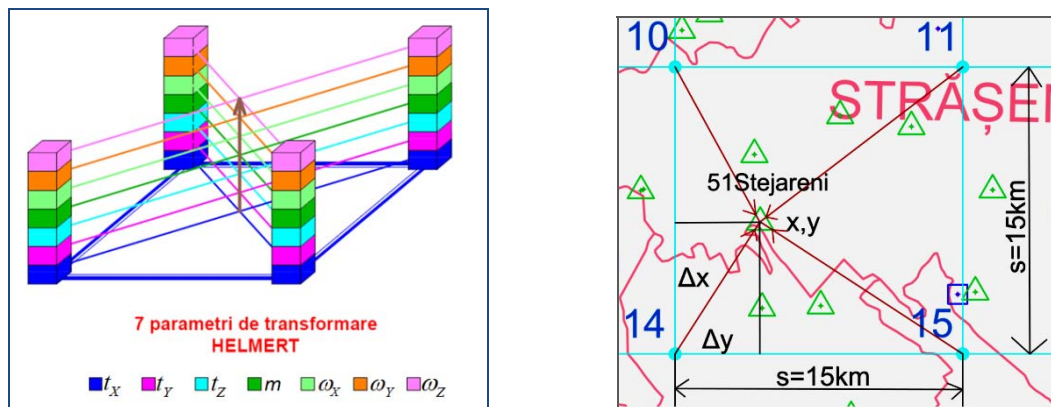


Fig. 3. Interpolation of transformation parameters diagrams

The interpolation was done for 3 geodetic sites those were not included in transformation parameters calculations: 51Stejareni and 196Vorniceni within cell 10-11-14-15; D12Romanesti Vest within cell 7-8-11-12 (Fig 3). For calculation of each of 7 transformation parameters sites were used bilinear interpolation formulae:

$$P_i(x, y) = a_{0_i} + a_{1_i}k + a_{2_i}l + a_{3_i}kl, \quad (3)$$

where:

$$\begin{aligned} a_{0_i} &= P_{14_i}, \\ a_{1_i} &= P_{15_i} - P_{14_i}, \\ a_{2_i} &= P_{10_i} - P_{14_i}, \\ a_{3_i} &= P_{14_i} + P_{11_i} - P_{15_i} - P_{10_i}, \\ k &= \Delta y/s, \\ l &= \Delta x/s, \end{aligned}$$

$P_{10_i}, P_{11_i}, P_{14_i}, P_{15_i}$ - transformation parameters for the cell 10-11-14-15 where the geodetic site is located ($i=1,2,3,\dots,7$);
 s – cell dimension.

The interpolated transformation parameters for all three sites are shown in table 2.

Table 2. Interpolated transformation parameters

ID	t_x, m	t_y, m	t_z, m	$m, 10^{-6}$	ω_x''	ω_y''	ω_z''
51 Stejareni	-9,199	150,590	96,817	-3,527	0,535	0,537	1,701
196 Vorniceni	-12,213	148,407	93,408	-2,740	0,223	0,356	1,293
D12 Romanesti Vest	-1,853	142,544	104,135	-4,644	2,487	1,502	3,505

Using transformation parameters from table 2 the ETRS89 geocentric coordinates X, Y, Z were calculated following equations below:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ETRS89} = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} + (1 + m) \cdot \begin{bmatrix} 1 & \omega_z & -\omega_y \\ -\omega_z & 1 & \omega_x \\ \omega_y & -\omega_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SC42} \quad (4)$$

Table 3. Differences between the calculated coordinates and official catalogue data

ID	X_{ETRS89}, m (calculated)	Y_{ETRS89}, m (calculated)	Z_{ETRS89}, m (calculated)	$\Delta X, m$	$\Delta Y, m$	$\Delta Z, m$
51 Stejareni	3827338,560	2068800,103	4648843,188	-0,033	-0,081	--0,063
196 Vorniceni	3821755,680	2070520,591	4652615,416	0,053	0,137	-0,103
D12 RomanestiVest	3807035,770	2081984,251	4659283,132	-0,290	0,272	0,033

Comparison of calculated coordinates using interpolated transformation parameters with catalogue coordinates calculated using regional transformation parameters shows a big differences around 30 cm of geodetic site D12 Romanesti Vest (Table 3).

4. Field testing

In order to clarify the errors nature a field test was carried out using GNSS receiver Trimble 5800 in RTK mode. The RTCM messages with differential corrections received from MOLDPOS service.

The geodetic sites were selected using geodetic database from official Land Relation and Cadastre Agency website <http://geoportal.md> (Fig. 4).



Fig. 4. Selected from geoportal geodetic sites

GNSS RTK measurements were carried out 3-10 minutes on the selected old classical triangulation sites with coordinates in SC42 and calculated ETRS89 coordinates using regional transformation parameters (Fig. 5).



Fig. 5. GNSS measurements on D12Romanesti Vest geodetic site

Field verification consisted in comparison of ETRS89 coordinates from GNSS RTK measurements and calculated ETRS89 coordinates from catalogue (Table 4) and also from grid interpolated transformation parameters (Table 5).

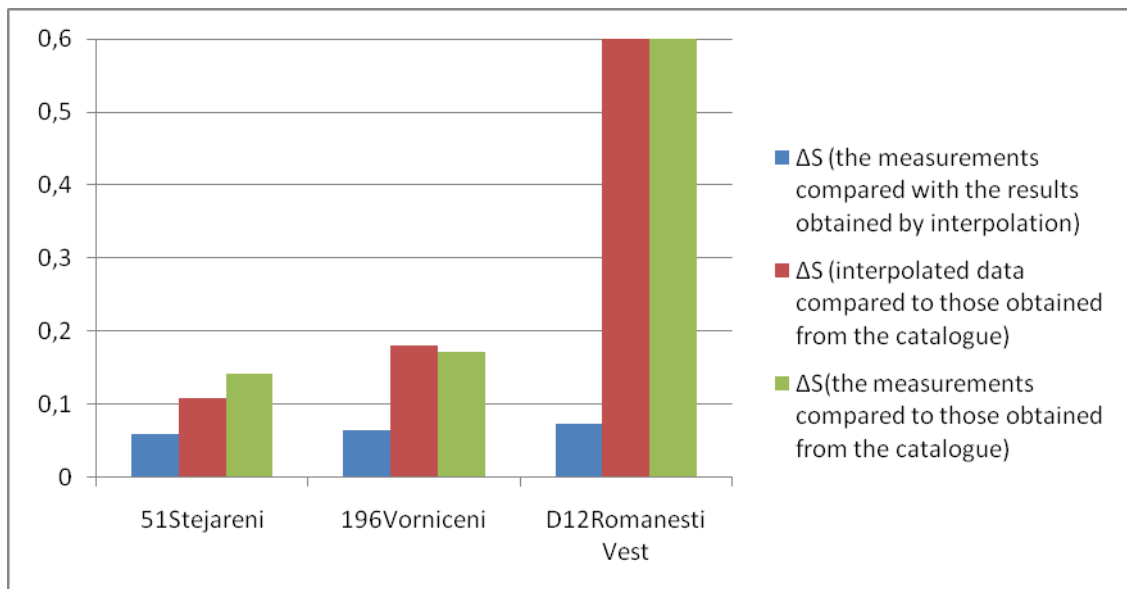
Table 4. Comparison of GNSS measured coordinates and catalogue coordinates

ID	X_{ETRS89}, m (Catalogue)	Y_{ETRS89}, m (Catalogue)	Z_{ETRS89}, m (Catalogue)	$\Delta X, m$	$\Delta Y, m$	$\Delta Z, m$
51 Stejareni	3827338,592	2068800,185	4648843,125	0,091	0,092	-0,059
196 Vorniceni	3821755,627	2070520,454	4652615,52	0,022	-0,162	0,052
D12 Romanesti Vest	3807036,059	2081983,68	4659283,165	0,347	-0,609	0,054

Table 5. Comparison of GNSS measured coordinates and grid interpolated coordinates

ID	X_{ETRS89}, m (Measured)	Y_{ETRS89}, m (Measured)	Z_{ETRS89}, m (Measured)	$\Delta X, m$	$\Delta Y, m$	$\Delta Z, m$
51 Stejareni	3827338,501	2068800,093	4648843,184	0,059	0,010	0,004
196 Vorniceni	3821755,649	2070520,616	4652615,468	0,031	-0,025	-0,051
D12 Romanesti Vest	3807035,712	2081984,289	4659283,111	0,058	-0,038	0,021

Analyses of field verification and comparison of resulting differences ΔS shows the big differences about 60 cm between GNSS measurements and catalogue coordinates calculated using regional transformation parameters. The smallest resulting differences ΔS about 6 cm for all three geodetic sites were obtained between GNSS measurements and calculated coordinates using grid interpolated transformation parameters (Fig. 6).

Fig. 6. Resulting differences ΔS from field verification

Further using of grid interpolated 3D Helmert transformation parameters will provide uniform coordinates transformation accuracy for all territory. For geodetic and cadastral applications ETRS89 geocentric coordinates X, Y, Z could be easy transformed to ellipsoidal coordinates φ, λ, h , MOLDREF99 coordinates $x(N), y(E)$ and normal heights H using well known transformation formulas and quasigeoid model.

5. Conclusions

The worldwide ongoing process of the establishment of high precise DGNSS-positioning services and respective GNSS-reference station networks, which are related to the globally GNSS-consistent ITRF, implies the replacement of the georeferencing in the old independent classical national reference frames by an ITRF-related one. Accordingly the new age of GNSS-positioning services - as interdisciplinary tool with a broad and growing spectrum of precise satellite positioning, navigation, mobile GIS and mobile IT applications –

requires the establishment and maintenance of a geodetic infrastructure for GNSS positioning services.

Development of transformation parameters data base in order to provide transformations from the old plan position data, which is related to a classical reference frame SC42 to the ETRS89 related horizontal georeferencing (φ , λ) concerns the establishment of modern GNSS-related databases for the infrastructure for spatial information in Europe (INSPIRE) including geodetic and cadastral surveying, GIS, navigation, urban planning, construction, transportation, meteorology, land management, precise agriculture, etc. The backward transformation of the ETRS89-related GNSS-position to an old classical datum SC42 is also needed, because the classical non-ETRS reference frames will still be relevant for at least one decade or more.

Taking in account that RTCM 3.1 transformation messages allows the MOLDPOS service to provide their users with all necessary data for positioning a grid transformation parameters data base from combined classical triangulation SC42 to MOLDREF99 and vice versa needs to be developed, using a new method of grid calculation and interpolation of Helmert transformation parameters.

Field testing of proposed method, carried out in the central part of country, shows centimeters level accuracy of coordinate's transformations from SC42 datum to MOLDREF99 and inverse. Results of this work shows the possibility to develop a transformation parameters database for all country territory improving the accuracy of coordinate transformation and giving the possibility to use existing large scale maps and charts.

6. References

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