ESTIMATION USABILITY OF THE FREE SOFTWARE FOR TRANSFORMATION OF GEODETIC COORDINATES BETWEEB LOCAL AND GLOBAL DATUMS-EXAMPLE OF THE ADRIATIC SEA

Duplančić Leder, Tea;

Faculty of Civil Engineering and Architecture, Matice hrvatske 15, 21000 Split, Croatia; e-mail: tleder@gradst.hr

Leder, Nenad

Hydrographic Institute of the Republic of Croatia, Zrinsko Frankopanska 161, 21000 Split, Croatia; e-mail: nenad.leder@hhi.hr

Abstract

The paper gives a brief outline of basic terms linked with global and local rotational ellipsoids and their datums as geoid approximations. It describes geodetic coordinate systems used to define the position of a point on the Earth. Several transformations are used to shift between local and global datums, but the Helmert and the Molodensky transformations are the most common ones. In order to estimate the usability of free software, 16 points were selected in a patterned distribution on the Eastern Adriatic coast. For each point, geodetic coordinates were transformed from the local ones to the WGS84 coordinates using a more accurate Helmert transformation (Trimble HYDROpro software with its parameters). After that, these coordinates were transformed using the Molodensky transformation, and the results were compared. The conclusion is that five free software products obtained satisfactory results, whereas one yielded somewhat poorer results.

Keywords: datum transformation, Helmert transformation, Molodensky transformation

1. Introduction

To date, in the Republic of Croatia, topographic maps and nautical charts have been produced on the local Helmannskoegel datum (Bessel rotational ellipsoid 1841). However, the modern GPS equipment for position fixing (geodetic coordinates) is based upon worldwide used satellite positioning methods, so that it gives position on the global WGS84 datum. As the satellite navigation is widely applicable nowadays (especially in maritime business), this calls for the production of a mathematical model of transformation from the global to the local datum and reversely. The world market offers a large number of software packages which calculate transformations from the local to the global datum, some of them being free and available on the internet.

Main objective of this paper is to help the users of satellite positioning (especially those lacking the essential knowledge of geodesy) in the interpretation of their measurements, and in the selection of high quality software products for the transformation of coordinates from the local to the global coordinate system.

The paper gives a brief outline of basic terms concerning the Earth's shape and size. Free software packages for the transformation of coordinates are examined and some of their possibilities presented. Finally, the results of free software packages for calculating transformations are compared to the results of the Trimble HYDROpro software used by the Hydrographic Institute of the Republic of Croatia.

2. Earth´s shape and geodetic datums

The Earth's physical surface has a very irregular and complex shape (geoid), which should be simplified and defined by means of a physical-mathematical model. The model which represents the approximation, i.e. the convergence to the shape of Earth's physical surface is called *rotational ellipsoid*. Rotational ellipsoid is defined by two parameters: the length of the semi-major axis a and the flatness of ellipsoid $f=(a-b)/a$ (Annoni et al., 2001).

The term of *geodetic datum* defines the shape and size of the Earth, as well as initial point and orientation of the coordinate system used for mapping of the Earth's surface (Dana, 2006). As a rule, it also includes the definition of *ellipsoid* as mathematical shape of the Earth. The datum helps to define the *reference coordinate system* in relation to the real world (SGA, 2004).

Ellipsoids of different dimensions and placements in space are used in geodetic practice; those which best fit to the entire Earth are called *global ellipsoids*, whereas those suitable for particular region or state are called *local ellipsoids*. Until 2004, the reference ellipsoid used in Croatia was the Bessel ellipsoid, defined in 1841, and the associated datum was the *Helmannskoegel* (*HER*). The Government of the Republic of Croatia then adopted the decision of establishing new official geodetic datums (European Terrestrial Reference System 1989 - ETRS89 with Geodetic Reference System 1980 – GRS80 as the official mathematical model) and flat cartographic projections (SGA, 2004). Parameters of the reference ellipsoids in official use or to be used in the Republic of Croatia are shown in Table 1.

Table1. - Parameters of the reference ellipsoids used in the Republic of Croatia

Parameter	GRS80	WGS84	Bessel 1841
a	6378137,00 m	6378137,00 m	6377397,155 m
f	1/298,257222101	1/298,257223563	1/299,15281285
Source	(SGA, 2004)	(NIMA, 1990)	(SGA, 2004)

In practice, geodetic datum is divided into the horizontal geodetic datum and the vertical geodetic datum, being the basis for computing the position on the Earth's surface or the height above the Earth's surface. Vertical geodetic datum is not the subject of this paper.

3. TRANSFORMATION OF COORDINATES

GPS receivers fix the positions of points on the WGS84 rotational ellipsoid. Some receivers can also calculate the positions of points into other datums. By using GPS technology, it is possible to fix the position in relation to the centre of the Earth mass. The World Geodetic System 1984 (WGS84; NIMA 1990) is a rotational ellipsoid centring the Earth through GPS satellite orbital elements. That is the reason why local datums are connected (parameterized) with the global WGS84 datum through transformation parameters.

Reference geodetic coordinates shown on different datums may result in a position error of some hundred meters (Fig. 1). Mathematical conversion of a geodetic position from one datum to another is called *transformation*. Among several models of transformation between the two datums, the following ones are usually used:

1. Helmert transformation (seven-parameter transformation), obtaining accuracy of 1 m for the area of the Republic of Croatia,
2. Molodensky transformation (three-parameter transformation), obtaining accuracy of 5 m for the area of the Republic of Croatia (Bašić et al., 2006).

Both models of datum transformation are shown on the geocentric coordinates.

Most transformation parameters for the Molodensky transformation which enables a shift from the local to the WGS84 rotational ellipsoid are available in the NIMA technical report (NIMA, 2000).

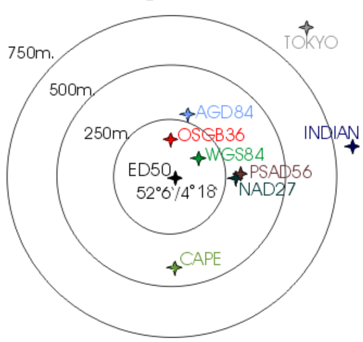

Figure 1. – Differences between the same coordinate shown in different datums (according to Dana, 2006)

3.1. Seven-parameter transformation of coordinates

Helmert transformation is also called the seven-parameter transformation. Parameters for the calculation of coordinate transformation represent a relation between the two datums: the shift of ellipsoid centre towards the centre of the Earth mass (*X*, *Y*, *Z*), the rotation around three coordinate axes (R_X, R_Y and R_Z), and the difference in scale between the two systems (S_C) (Fig. 2). The advantage of this method is greater accuracy in calculating transformation as compared with the three-parameter transformation.

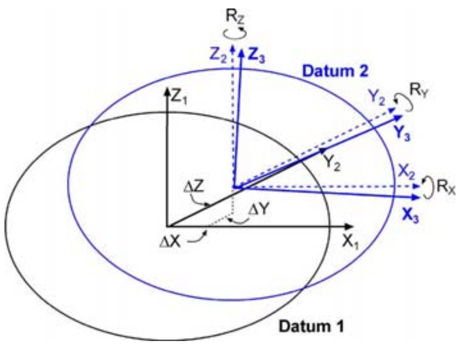

Figure 2. – Seven-parameter transformation

3.2. Three-parameter transformation of coordinates

The Molodensky or 3-parameter transformation is commonly used with manual GPS receivers and GIS. The formula is simple, assuming that the transformation between the local and global datums can be represented by a shift of the ellipsoid centre towards the centre of the Earth's masses □X, □Y and □Z (Fig. 3). In its technical report (1990), the NIMA gives the formula for the Molodensky parameter transformation between local datums and WGS84:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (1)$$

where *X'*, *Y'*, *Z'* are geocentric rectangular coordinates in System 1, *X, Y, Z* are rectangular coordinates in System 2, while *X*, *Y*, *Z* are differences between the system origin.

Standard Molodensky transformation is one of most widely used methods for the transformation of geodetic coordinates from one datum to another. It is less accurate than the Helmert transformation (Bašić et al., 2006). Molodensky transformation has the advantage of a simple computation. It should be pointed out that this method is incorporated within most GIS packages, as well as into most GPS receivers.

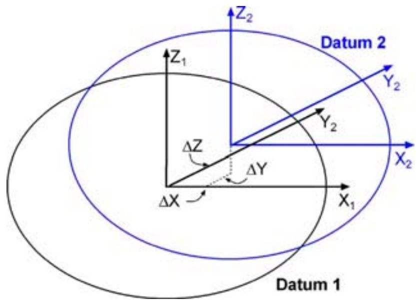

Figure 3. - Three-parameter transformation

4. Main Characterics of free Software

Many free programs for computing the transformation of geodetic coordinates between different datums are available on the internet, which is particularly important to a wider circle of GPS data users. Such programs are called *free software* and they can be used without restrictions. Internet also offers many relatively cheap programs for the transformation of coordinates which allow a free use of program for a restricted period of time (mostly one month). Such software generally supports more than 200 geodetic datums, and the source material for parameters is NIMA (2000). Transformation parameters used in free programs are shown in Table 2.

Table 2. – Transformation parameters used in free programs and their source

	PCTrans	EasyTrans	TatukGIS	Transdat	Geotrans	ILWIS
ΔX (m)	682	682	-	653	682	-
ΔY (m)	-203	-203	-	-212	-203	-
ΔZ (m)	480	480	-	449	480	-
Source	NIMA, 2000	NIMA, 2000	NOAA, 1995	MapRef (URL 1)	NIMA, 2000	NIMA, 2000

4.1. PCTrans 4.1

PCTrans was developed by the Netherlands Hydrographic Service (URL 2). The program works with several map projections, and provides datum transformation, geodetic and loxodrome calculations, and area calculations where Earth curvature needs to be taken into account. Parameters for 235 different datums are already built in, and this list can be extended with one’s own 3- or 7-parameter set of transformation data. It is possible to calculate transformations between projections. The program has a possibility of plotting the calculated coordinates on screen. Of all examined programs, this program offers most possibilities.

4.2. EasyTrans Version 1.27

EasyTrans Version 1.27 is a simple and intuitive program for computing the transformation of coordinates, being available at the web site (URL 3). The program was written in German language and supports 220 ellipsoids. EasyTrans supports both professional and leisure version for computing the transformation of coordinates. A version in English language with limited number of ellipsoids and datums (Hermannskoegel is missing) is also available. Major disadvantage is the usage of limited duration (30 days).

4.3. TatukGIS Calculator Coordinate Conversion Calculator

This program was developed by *TatukGIS Developer Kernel* (DK). Current version 1.2.0.30 (URL 4) supports 24 projections and 225 datums, and the next version 2.0 is expected more projections and datums. The program is simple to compute, yet with one fault – the transformation result is calculated to one decimal place. Transformation is calculated very quickly but entering is a little complicated. Another defect is that the program lacks the Help feature.

4.4. Transdat Version 10.15

The program was developed by Killet Software Ing.-GbR, Germany (URL 5). Web site of the program includes a complete list of coordinates and reference systems supported by the program. The program allows entering reference ellipsoid parameters. Geographic coordinates for transformation can be entered into the program using keyboard, but also by means of database file formats. It is possible to transform the coordinates obtained from GPS receiver connected to the computer via interface. The program documentation is available in English and German.

4.5. Geotrans 2.4.2

Geographic Translator - GEOTRANS, was developed by the US Army Topographic Centre, Geospatial Information Division, and National Geospatial Intelligence Agency (URL 6). The program allows a simple conversion of geodetic coordinates between a large number of coordinate systems, projections and datums and supports 230 datums and 29 projections.

4.6. ILWIS Datrans - Elipsoidal Datum transformation Version 1.1

ILWIS is a Dutch program developed by the International Institute for Geo-Information Science and Earth Observation - ITC Enschede (URL 7). It is specified that the 7-parameter transformation is used as a transformation method, which mast be entered by user. Coordinates are entered in degrees and parts of degrees. Calculation accuracy is somewhat lower, which is a serious disadvantage of this program. In our experience, calculation has proved to be inconvenient.

4.7. Programs without Croatian datum

Many programs that are available on the internet but lacking the Croatian national datum were not tested, such as: Blue Marble Geographic Calculator, Feral map projection and datum transformation utility, and SHPTRANS.

5. Methods

Croatian part of the Adriatic occupies an area approximately from 45ºN 13ºE to 41º,5N 19ºE. Sixteen points were selected as check points to calculate the transformation of coordinates, being evenly arranged over the territory of the Croatian part of the Adriatic Sea (Fig. 4). In Trimble HYDROpro Version 1.4, coordinates of the selected points were converted from the local Helmannskoegel Datum into WGS84 Datum, using Helmert transformations. Transformation parameters for the Helmert transformation were obtained from the Faculty of Geodesy in Zagreb.

Trimble HYDROpro Version 1.4 - Hydrographic software was developed by Trimble Navigation Sunnyvale, California, USA. The program was finalized to serve computations of coordinate transformation between Helmannskoegel and WGS84 at the Hydrographic Institute of the Republic of Croatia by entering 7 parameters.

Essential prerequisite for this operation is that the results of coordinate transformation using Trimble HYDROpro Version 1.4 is accurate, as it is a professional software package. Trimble software package was therefore taken as an etalon.

Furthermore, transformations of coordinates between local datum and WGS84 were calculated for the above mentioned 16 points (Fig. 4) by means of free programs described in Chapter 4, and the obtained values were compared with the coordinates transformed using Trimble HYDROpro.

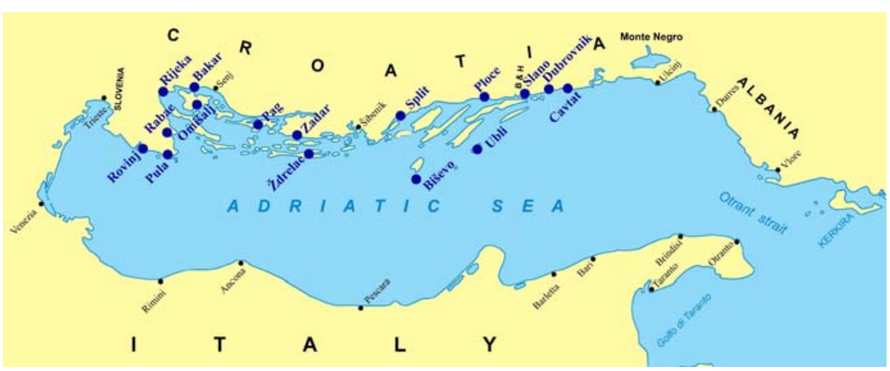

Figure 4. – Location of selected 16 points

6. Results

Differences between the coordinates obtained by 7-parameter transformation in Trimble HYDROPro and the coordinates obtained by the tested free software using 3-parameter transformation are shown in Figs. 5 and 6. The differences are shown on WGS84 in seconds. Analysis of mean differences in geodetic coordinates reveals that ILWIS program produces much worse results than other tested programs, so that it will be ignored in further analyses.

Mean differences of geodetic latitude range between 0",066697 (PCTrans) and 0",110841 (Transdat), while mean differences of geodetic longitudes range from 0",035505 (Transdat) to -0",106049 (EasyTrans).

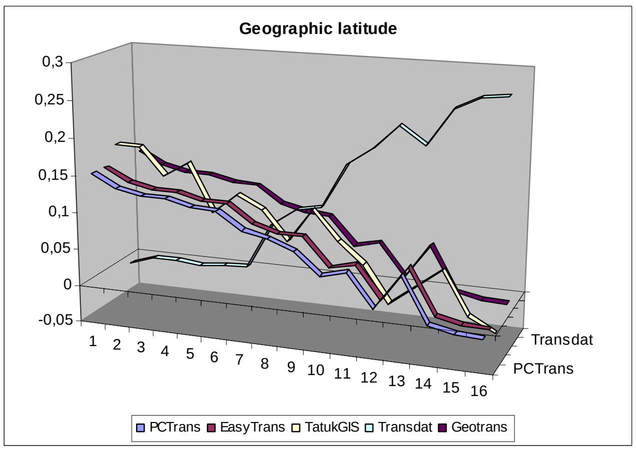

Figure 5. – Differences between the coordinates obtained by 7-parameter transformation (HYDROPro) and the coordinates obtained by means of free software using 3-parameter transformation - φ component

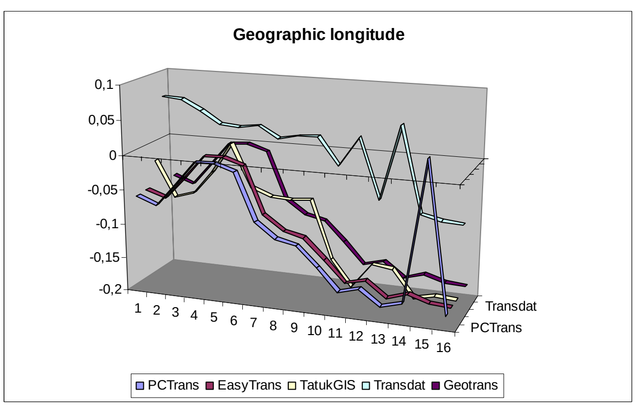

Figure 6. - Differences between the coordinates obtained by 7-parameter transformation (HYDROPro) and the coordinates obtained by means of free software using 3-parameter transformation - λ component

7. Conclusión

For transformation of coordinates between the local Helmannskoegel Datum and the global WGS84 Datum, free programs PCtrans, EasyTrans, TatukGIS, Transdat and Geotrans are recommended, while ILWIS program has much worse results. It should be pointed out that the results produced by free programs are adequate to meet the needs of most GPS users.

Mean differences of coordinates between the local and global WGS84 datum obtained by Trimble HYDROpro Version 1.(7-parameter transformation) are as follows: for geodetic latitude 0",079815 (3,341 m), and for geodetic longitude 17",193777 (385,846 m). The above mentioned values were calculated from a representative sample of 16 points evenly arranged along the Adriatic coast.

For all those using GPS receivers in conjunction with nautical charts, according to recommendations of the International Hydrographic (IHO), Hydrographic Institute of the Republic of Croatia, as publisher, enters corrections to WGS84 Datum. Since 2004, corrections have been entered on all charts with every new edition of that chart. Positions obtained from satellite navigation systems referred to WGS84 Datum, to harmonize with charts, should be corrected as follows: for North Adriatic by about **0.01 minute north** (0.6 sec) and **0.28 minute east** (16.8 sec), for Middle Adriatic by **0.01 minute north** and **0.29 minute east** (17.4 sec), and for South Adriatic by **0.01 minute north** and **0.30 minute east** (18 sec).

Comparing the results of coordinate transformation between local Croatian and WGS84 datums presented in this paper and those published at the official nautical charts, it can be concluded that for précised positioning during navigation free programs PCtrans, EasyTrans, TatukGIS, Transdat and Geotrans should be used.

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