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Contribution to the Datum Transformation of GPS Results for GIS Applications

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Contribution to the Datum Transformation of GPS Results for GIS Applications

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Abstract

The paper describes a modified procedure for the transformation of GPS results into the local geodetic datum. The technique is based on three-dimensional difference vectors between GPS coordinates and local coordinates at control points well-distributed over the area of interest. Each component of these difference vectors is plotted in form of isolines. Thus, the difference vector can be interpolated for arbitrary points where accuracies at the sub-decimeter level are achievable.

Zusammenfassung

Die Arbeit beschreibt ein modifiziertes Verfahren zur Transformation von GPS-Ergebnissen in das lokale geodätische Datum. Die Technik basiert auf den dreidimensionalen Differenzvektoren zwischen GPS-Koordinaten und den lokalen Koordinaten an gut verteilten Kontrollpunkten. Die Komponenten dieser Differenzvektoren bilden die Eingangsdaten für Isolinienplots. Der Differenzvektor für beliebige Punkte kann daher aus diesen Plots interpoliert werden, wobei Genauigkeiten im Subdezimeterbereich erhalten werden können.

1. Preamble

In the fall of 1994, the project „Application of Satellite Positioning and the Development of Data Bases for GIS" was initiated. The project is part of the Austrian-Hungarian Intergovernmental Science and Technology Cooperation Programme. The Hungarian party to the project is the Department of Geodesy (Prof. J. Ádám) of the Technical University Budapest while Austria is represented by the Division for National Surveying and Landinformation (Prof. B. Hofmann-Wellenhof) of the Technical University Graz. The present paper is one result of this bilateral research project.

2. Introduction

Nowadays, GPS is a cost-effective technique to position GIS objects. The ambiguity problem inherent to carrier phases is eliminated if only code pseudoranges are considered. Differential techniques (DGPS) using smoothed code ranges facilitate accuracies up to some decimeters. For non-geodesists, GPS positioning suffers from the fact that GPS results are obtained as geocentric Cartesian coordinates related to the World Geodetic System 1984 (WGS-84). The transformation of these coordinates into the local geodetic datum is usually performed by a 7-parameter similarity transformation, cf [4]. These parameters comprise 3 translations, 3 rotations about the coordinate axes, and 1 scale factor. If the transformation parameters are unknown, they can be determined by a least squares adjustment with the aid of (at least three) common points. For these points, the coordinates must be given in the WGS-84 and in the local system as well. However, due to inhomogeneities in the national geodetic control networks, one set of transformation parameters is generally not sufficient for large areas and high accuracy requirements. For GIS applications where lower accuracies are required, the 7-parameter transformation could be replaced by a modified 3-parameter transformation.

In the sequel, this technique is described in detail. An application to the Hungarian territory demonstrates the accuracy potential of the method.

3. Modified datum transformation

3.1. Basic principle

The impact to the present investigation was given by [3] who proposed the procedure in the context with Doppler positioning. The technique is based on the determination of (position dependent) shift vectors $\Delta\underline{X}_i$ in each common point. These vectors are defined by the differences

$$\Delta\underline{X}_i = \underline{X}_{iLS} - \underline{X}_{iGPS} \qquad (1)$$

where $\underline{X}_{iLS}$ denotes the position vector of the common point P_i in the local system while $\underline{X}_{iGPS}$

is its position vector in the WGS-84 system. Note that the latter is obtained directly from the GPS observations. The components of the vector $\underline{X}_{LS}$ can be computed by the relations

$$\underline{X}_{LS} = \begin{bmatrix} (N+h) \cos \varphi \cos \lambda \\ (N+h) \cos \varphi \sin \lambda \\ \left(\frac{b^2}{a^2} N+h\right) \sin \varphi \end{bmatrix} \quad (2)$$

where φ, λ, h are the ellipsoidal latitude, longitude, and height of the point under consideration. The semiaxes of the ellipsoid are termed a,b and

$$N = \frac{a^2}{\sqrt{a^2 \cos \varphi^2 + b^2 \sin \varphi^2}} \quad (3)$$

denotes the radius of curvature in the prime vertical.

In scalar form, Eq. (1) reads

$$\begin{bmatrix} \Delta X_i \\ \Delta Y_i \\ \Delta Z_i \end{bmatrix} = \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix}_{LS} - \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix}_{GPS} \quad (4)$$

and, formally, the equation can be considered as a similarity transformation with the rotations and the scale factor $\Delta\underline{X}_i$ constrained to be zero. However, the position vectors for the common points are not averaged (this would correspond to a least squares adjustment) but are considered as position dependent terms. It should be noticed that each $\Delta\underline{X}_i$ will give a correct datum transformation for the common point P_i although large rotations and scale factors may exist. The components of $\Delta\underline{X}_i$ are then entered into a plotroutine to construct contour lines. These contour (or isoline) plots are used for the interpolation of $\Delta\underline{X}$ in others than the common points.

According to Eq. (1), the interpolated shift vector must be added to the observed GPS position vector to obtain the position vector

$$\underline{X}_{LS} = \underline{X}_{GPS} + \Delta\underline{X} \quad (5)$$

of a new point related to the local system.

Relations inverse to those in Eq. (2) lead to the ellipsoidal (or geodetic) coordinates φ, λ, h of the new points. Details can be found in [4]. Note that the components of $\Delta\underline{X}$ could also be expressed in terms of $\Delta\varphi$, $\Delta\lambda$, Δh so that geodetic coordinates may be directly transformed.

In the last step, the ellipsoidal latitude and longitude are mapped into plane coordinates and the geometrically defined ellipsoidal height is converted into a physically defined height such as the normal height. The mapping depends on the desired projection system. The systems used in Hungary are described in [6]. The height conversion requires information on the geoid. For Hungary, such information is provided for example by a map of geoidal heights prepared by [5].

The modified datum transformation works even for large areas. However, the accuracy depends on the proximity of the new point to a common point. Furthermore, increased accuracies are achievable if the isolines show a smooth behaviour.

3.2. Shift isolines for Hungary

The procedure was tested for the Hungarian territory using 43 common points. The GPS coordinates of these points were obtained by a common adjustment of the (civil) National GPS Frame Network (OGPSH) and the Military GPS Network (KGPSH) in the European Reference Frame (EUREF-89), cf. [2]. The coordinates in the local system are related to the Hungarian National Datum HD-72. The distribution of the common points is shown in Fig. 1.

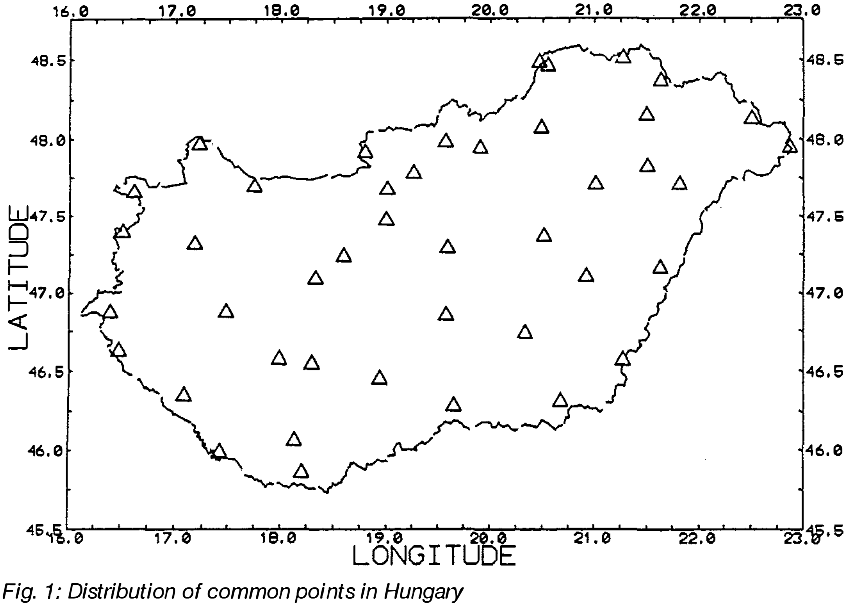

Fig. 1: Distribution of common points in Hungary

For each common point, the shift vector $\Delta\underline{X}_i$ was computed according to Eq. (1). Each component of $\Delta\underline{X}_i$ served as input for an isoline plot program. As output, contour maps were obtained which are shown for the components ΔX, ΔY, ΔZ in Fig. 2. The components are given in meters and the contour interval is 0.05 m.

The change of the shift components over the Hungarian territory is in the range of one meter. This is a consequence of tilts between the two reference frames. Due to the smooth behaviour of the isolines, cf. Fig. 2, the shift components can be interpolated to a high accuracy everywhere in Hungary. The plots could be digitized to provide the corrections automatically during field operations. The plots may also be used in future precise DGPS applications where accuracies in the sub-decimeter range are achievable.

It is remarkable that shift isolines for Hungary were published already by [1] for the transformation of Doppler results into the national datum. As it was expected, the respective plots show the same characteristics as those in Fig. 2; however, the accuracy was at the meter level only.

3.3. Shift isolines for Austria

A similar investigation for the Austrian territory is performed in the course of a student's seminar. Note that a single set of parameters for the 7-parameter similarity transformation would lead to accuracies not better than some meters in Austria. The application of the modified

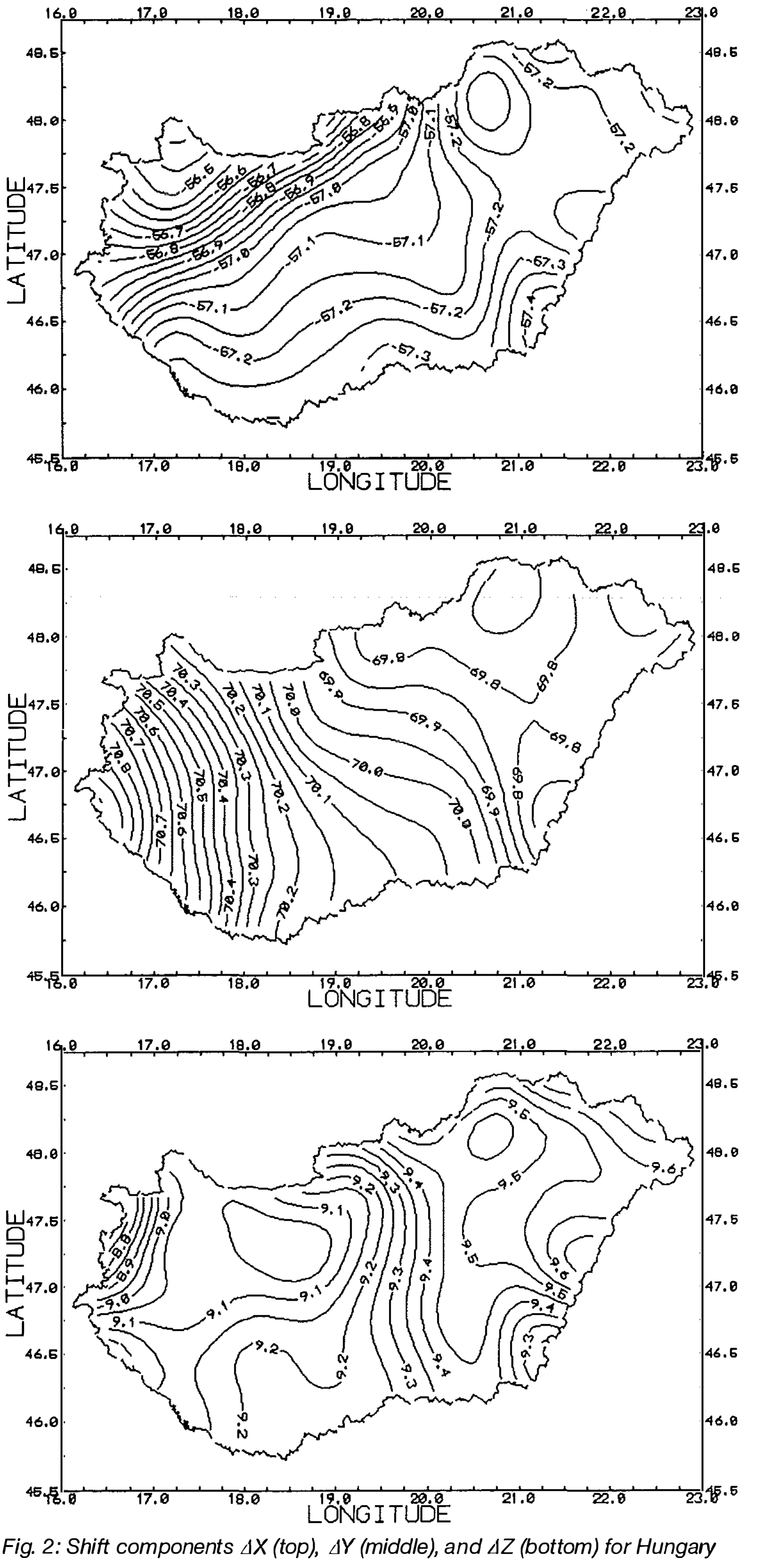

Fig. 2: Shift components ΔX (top), ΔY (middle), and ΔZ (bottom) for Hungary

transformation using position dependent translations will improve the accuracy by at least one order of magnitude. One reason for this optimistic estimation is the fact that a dense grid consisting of about 350 common points is available. This grid was established by an Austrian consortium of licensed surveyors during the Austrian Reference Frame (AREF) GPS campaign in June 1996.

4. Conclusions

The modified technique for the datum transformation is an easy-to-use procedure which can be applied without specific geodetic knowledge. The simplicity is based on (digital or analogue) isoline maps. The smoothness of the isolines is a direct indicator for the quality of the interpolated shift vectors in the area under consideration. The transformation of GPS coordinates into Cartesian coordinates related to the national datum requires only simple additions. The transformation of these coordinates into ellipsoidal or plane coordinates can be performed routinely.

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