Two computer programs for official datum transformation and geoid interpolation in Croatia

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Abstract. *The paper presents the procedures used in the development of the two utility computer programs: IHRG2000 for the interpolation of HRG2000 geoid at the territory of the Republic of Croatia and DAT_ABMO for the transformation of coordinates between the Croatian local geodetic datum based on Bessel's ellipsoid (called HDKS – Croatian State Coordinate System) and global ITRSxx i.e. ETRSxx datums that are defined referring to GRS80 ellipsoid.*

1. Introduction

Resulting from an increasing number of GPS-technology users in Croatia, a special scientific and profession project has been made by the State Geodetic Administration and the Department for Geomatics at the Faculty of Geodesy, University of Zagreb that yielded two separate computer programs: IHRG2000 and DAT_ABMO. The programs are written in Visual Basic 6.0 (Microsoft Group 2000) and they support all the latest Windows platforms.

In (Bašić 2001) a new solution was presented for the geoid surface at the entire territory of the Republic of Croatia HRG2000. In order to provide its simple application, it is necessary to make a computer program for interpolation. These efforts resulted in the application IHRG2000 that enables quick and accurate determination of geoid in any point at the territory of the Republic of Croatia. The program has been supplemented with the graphic maps of the Republic of Croatia that can be used for approximate input of point, and by with the map of the Republic of Croatia having clearly marked geoid contours where all interesting points and the results can be seen.

The second computer program DAT_ABMO is designed for the transformation of coordinates between diverse geodetic datums and measuring epoches. Primarily it is provided to the GPS users, but not exclusively. With the program it is possible to calculate own transformation parameters, to give from the past known transformation parameters and transform the coordinates between different global datums and Croatian State Coordinate System, and to enable several conformal map projection calculations, like UTM and Gauss-Krueger projection.

2. IHRG2000 computer program for the interpolation of HRG2000 geoid

The basic purpose of the program is the interpolation of HRG2000 geoid and the presentation of the results on screen, their storage on a disc and a print out. In the case of HRG2000 model, we deal with absolutely oriented geoid surface with the internal accuracy running up to ± 1-2 cm at the most of the territory, and up to ±5 cm on the edge (Bašić 2001).

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The computation field has been selected in the area between 42.0° and 46.6° of latitude and 13.0° and 19.5° of longitude, so that it covers the whole territory of Croatia. The size the raster within which the geoid prediction has been made is 60"x90".

2.1 Methods of interpolation

Interpolation is the procedure of computing the values of the function in a given point that is positioned within the set of points with known requested values, and it can be regarded as a special case of approximation. In the IHRG2000 program there are two possibilities of interpolation: bilinear and spline (Bašić, Šljivarić 2003).

Bilinear interpolation. There is a set of points given in the plane (x_1,y_1), (x_2,y_2), …, (x_n,y_n) having the property $x_1<x_2\ldots<x_n$. It is necessary to construct the function: $[x_1,x_n]\rightarrow R$ for which it is $y_i=f(x_i)$ for each $i=1,2,\ldots,n$. The function f gets such values to allow a simpler and smoother function between the given points. One way of interpolating is by all means the linear interpolation. Let the interval [a,b] be divide by nodal points $x_1,x_2,\ldots,x_n$ so that $a=x_1<x_2,\ldots,x_n=b$. Each point x_i on the abscise is associated with the ordinate y_i. Let us draw a straight line function through the points (x_i,y_i) and (x_{i+1},y_{i+1}):

$$S(x)=\frac{y_{i+1}-y_i}{x_{i+1}-x_i}(x-x_i)+y_i,\quad x\in[x_i,x_{i+1}],\ i=1,2,\ldots,n-1, \tag{2.1}$$

that is called *interpolation linear spline,* and its graph is a polygonal line passing through the given points (ibid.).

Spline interpolation. Each continuous function f at the closed interval [a,b] can be well approximate with some polynomial. The continuity of the function and its first two derivations is manifested geometrically in the continuity of a graph and in the existence and continuous changing of a tangent and curvature in each point. The function $s\in C^2[a,b]$ with partly constant third derivation where s(x) is a third-degree polynomial:

$$s(x)=a_i+b_i(x-x_i)+c_i(x-x_i)^2+d_i(x-x_i)^3,\quad x\in[x_i,x_{i+1}] \tag{2.2}$$

is called *cubic spline*. Let $f\in C^2[a,b]$ be a real function. If it is $s(x_i)=f(x_i)$, $i=1,2,\ldots,m$ and if for each $x\in[a,b]$ the function s(x) i f(x) are not "too much different", we have got the *interpolation cubic spline*. The third-degree polynomial is defined with four parameters, and *m+1* nodes determine *m* intervals, i.e. *m* such polynomials. In order to construct a spline, it is necessary to determine altogether *4m* parameters. The expression for the third-degree polynomial s(x), and the relation $s(x_i)=f(x_i)$ yield *4m-2* conditions. The unanimous solution requires two additional conditions. If we choose that $s''(x_1)=s''(x_m)=0$, i.e. that the other derivations are equal zero for marginal values, then we have defined the *natural cubic spline* (ibid.).

2.2 Presentation of the program IHRG2000

After initiating the program IHRG2000, the **initial form** is shown on the screen (Fig. 2.1). The program is ready for data input and for the changes in computation parameters. The most important input values are latitude and longitude in DEG (degrees and decimal degree parts) or DMS (degree, minutes and seconds) units. They are entered in three ways: by the keyboard, disc, and from the map. Unnecessary data from the list are removed with deleting commands.

When entering the coordinates by **keyboard**, the following issues are entered: point name, latitude and longitude, and ellipsoid height or altitude. If the box for the elevation of point is left empty, the program adds the value zero to the elevation (it does not affect the interpolation result). Using the command *Unesi (Enter)*, we enter the values from the box into the Input list. The boxes for latitude and longitude do not allow the signs for text to be entered, neither the special sign (!,$,%,&,*, …). Two equal points or two points of the same name cannot be entered onto the list.

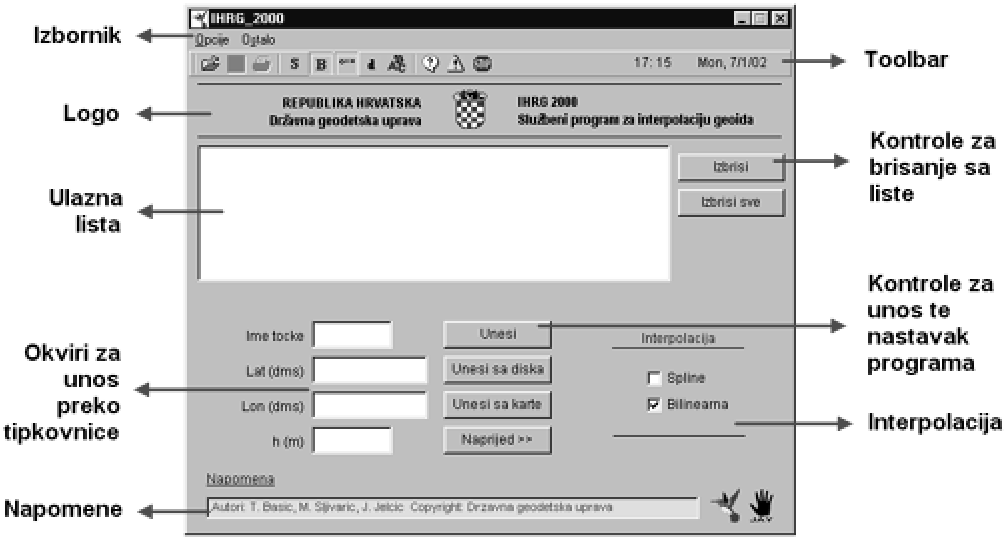

Fig. 2.1 Initial form of IHRG2000 program

By activating the key *Unesi sa diska (Enter from disc)*, the form for entering the documents with data is opened. The documents of various extensions are supported (.inp, .txt. or .all). After selecting the needed document, the input list is filled in. The program determined on the basis of the firs row in the document which units were used (DEG or DMS) for the data to be entered onto the list. Fig. 2.2 shows the example of the input files. The first row contains the mark "DEG" or "DMS" defining in which units would the program recognise the coordinates. The first row contains the point name, the second contains ellipsoid width, the third ellipsoid length, and the last ellipsoid height or altitude.

If the third possibility *Unesi sa karte (Enter from map)* is used (Fig. 2.1), the points for interpolation can be taken directly from the map of the Republic of Croatia (Fig. 2.3). Clicking the left button of the mouse, we enter the momentary values of the cursor position (with the accuracy up to 3 angle minutes) into the boxes on the right side of the form. The name of the point should be entered and the command "Unesi (Enter)" clicked for entering it onto the map list. The name of the point appears on the list. Clicking the right button of the mouse, we replace the map of Croatia by a large-scale map, which also increases the accuracy of defining the cursor that now runs up to 1 angle minute. By clicking the right button of the mouse once again, we get back the presentation of the small-scale map. The back command closes the form, and all points from the list are entered onto the input list of the initial form.

The selection of the interpolation methods is made in the program in three ways. Four various combinations of postulations are possible, but it should be pointed out that in case both spline and bilinear interpolation are included, the other one is done only in the case of failed spline interpolation (e.g. to close of the edge of the computing area). As a rule, spline is more accurate form of interpolation, and bilinear interpolation is done mostly with a larger number of data, because its performance is quicker. The differences in the result are of millimetre size, and in the case of geoid interpolation, both methods can be regarded as equally good.

```
DEG
30       43.0183740033  17.1299478275   575.098
A        43.0314326738  17.1597162831    49.813
B        42.2591045265  18.1594985337    47.024
E        42.5309116175  18.0291382460   244.514
EE       45.2145853494  15.2475528135   108.692
F        45.1347699507  15.0287847519    56.345
G        45.1038870659  14.0271988413    51.853
O        45.2109796785  14.0310895250   367.979
T181     45.2849408994  14.2019678897  1446.386
Z        45.1735447961  14.0281397008   383.459
30a      44.0183740033  15.1299478275   575.098
Aa       44.0314326738  15.1597162831    49.813
Ba       44.0591045265  15.1594985337    47.024
Ea       44.0309116175  15.0291382460   244.514
EE       44.2145853494  15.2475528135   108.692
Fa       44.1347699507  15.0287847519    56.345
Ga       44.1038870659  15.0271988413    51.853
Oa       44.2109796785  15.0310895250   367.979
T181a    44.2849408994  15.2019678897  1446.386
Za       44.1735447961  15.0281397008   383.459
101a     45.4314326738  18.3597162831    49.813
102a     45.1591045265  18.5594985337    47.024
104a     42.2145853494  13.2475528135   108.692
105a     45.4347699507  15.4287847519    56.345
```

Fig. 2.2 Example of the input file

Fig. 2.3 The form for defining the coordinates from the map

The transformations through *DEG and DMS* functions can be retrieved from the menu (*Options →Units →DMS* or *DEG*) or from toolbar (Fig. 2.1), which provides quick conversion of units on the input and output list. The results of interpolation are obtained after activating the command *Naprijed (Forwards)* and are printed on the **Output List Form** (Fig. 2.4). The marks "S", "B" or "N", written on the list next to the interpolation results, denote the interpolation method. "S" is the mark for spline, "B" for bilinear and "N" is the mark for failed interpolation (the point is outside of the area of possible interpolation, and the solution get the "stupid" value 99.99 added).

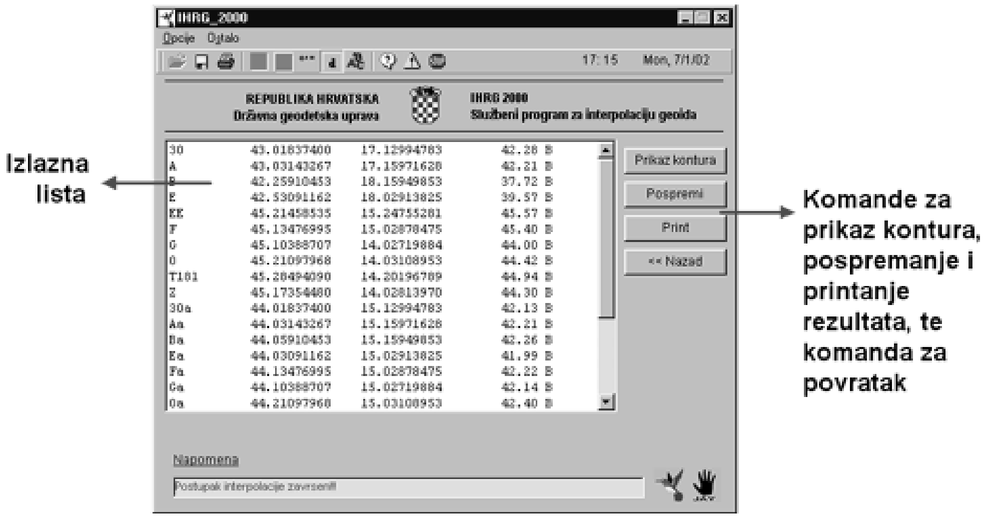

Fig. 2.4 Presentation of the output file

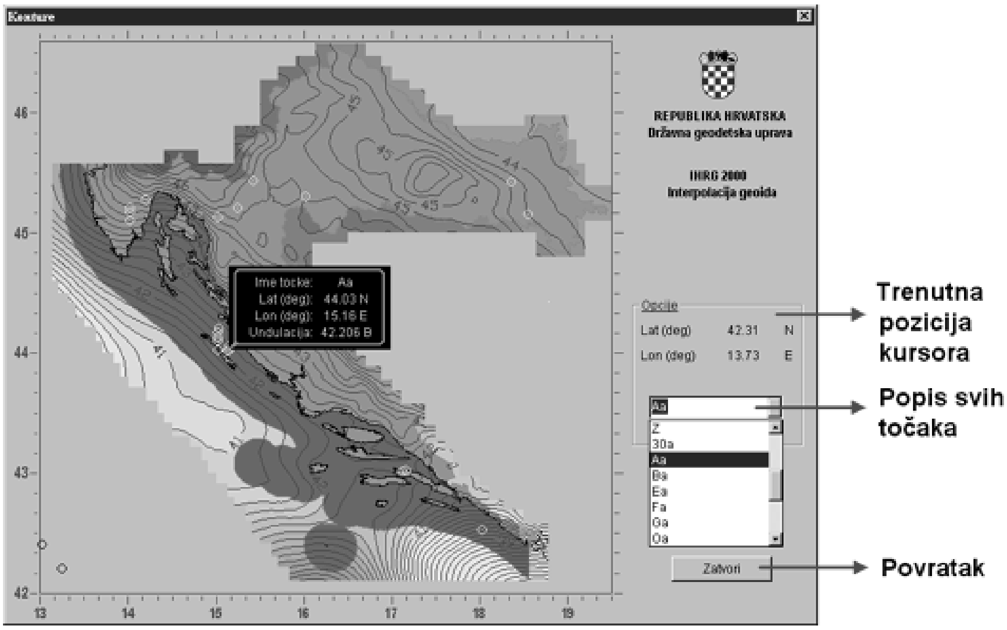

Fig. 2.5 Presentation of contours

After activating the command *Prikaz kontura (Contour presentation*, Fig. 2.4), all points are presented that are in the output list on the contour picture (Fig. 2.5). The points are delineated within yellow or black circles. The yellow colour denotes successful interpolation, and the unsuccessful one is presented with black colour. Pressing the left mouse button we call for the information about the point that closest to the cursor position on the map at that moment. The information about the point can be retrieved from the list of points as well. The results of interpolation are saved onto the disc or some other data transfer medium by pressing the key *Pospremi (Save)* which is followed by the adequate from. The documents are saved with the extension ".out", ".txt" or ".all".

Printing of input and output list enables the function *Print* (Fig. 2.4). It is necessary to choose the printout that we want to print, the number of copies and click the command "O.K.".

The program IHRG2000 enables also the change of screen resolution which is performed by activating the command **Options** on the Toolbar of the initial form (Fig. 2.1), and of the function **Resolution.** After that, we have to decide between two resolutions: 800x600 dpi and 1024x768 dpi. Additionally, it is possible to change the shape and the size of font by pressing the function **Font** under **Options.**

3. Presentation of the program DAT_ABMO

The development of this program started in 1998 when already existing FORTRAN program «databmo.for» (author Ž. Bačić) is adjusted to the operation in the Windows surroundings and translated into Visual Basic (seminar paper by M. Šljivarić within the frame of the course GPS in GIS). Further implementation and improvement was carried out on the program at the end of the year 2000 (seminar paper of J. Jelčić, the undergraduate ABD at that time). On the basis of the original code of the other FORTRAN program «T7.for» (author T. Bašić), during the year 2001 the program experiences its final form and intention.

The intention of the program can be divided into the following tasks: spatial transformation of coordinates depending on time (Boucher-Altamimi formulas), spatial transformation of coordinates not depending on time (Helmert's 7. parameter spatial transformation), spatial transformation of coordinates depending on time caused by movements of the geological plate EURA (according to the parameters form the model NUVEL-1A), the computation of the parameters from Helmert's spatial transformation on the basis of identical points in both datums (adjustment of indirect measurements by using the least squares method), conversion of various coordinate record forms (Cartesian and ellipsoid – degree sexagesimal and decimal, as well as centesimal), cartographic projecting of ellipsoid or Cartesian coordinates into some of the offered cylindrical, conformal projections (transverse Mercator: GK-15E, GK-18E, GK-16.5E, as well as UTM-33N and UTM-34N).

3.1 General about geodetic datums and their transformation

Geodetic datum is a mathematical representation of the size and shape of the Earth, and it is presented by a set of parameters defining the shape of the reference surface, as well as the position of the Earth's body in the space (Bašić 2002). Geodetic datums are divided into local and global (geocentric).

Croatian State Coordinate System (HDKS) is a local datum based on the triangulation measurements and the adjustment of the Military and Geographic Institute from Vienna at the end of the 19^{th} century. All computation has been carried out on Bessel’s ellipsoid (1841), and the datum has been defined using astrogeodetic method over the fundamental point Hermanskögel near Vienna. Gauss-Krueger conformal cylindrical projection has been additionally accepted in 1924 for computing plane coordinates, whereby the territory of Croatia has been mapped in two zones with the initial meridian at 15º (5. zone) and 18º (6. zone).

Global geodetic datum approximates in the best way the size and the shape of the Earth as a whole, and defined it in such a way that the ellipsoid centre coincides with the geocentric and that the rotational axis of the Earth coincides with the small semi-axis of the ellipsoid.

In DAT_ABMO program there are three various procedures of coordinate transformation:

- Transformations between official observation frames (e.g. between ITRF94 and ETRS89), where the transformation parameters are saved in the file GF_EUREF2001.TP coming together with the program – when using that kind of transformation, the sections *Input datum* and *Output datum* should obligatorily be specified in the program, because the same parameters are prescribed this was as well in the above-mentioned file.

- For the other transformations, either user ones, or those with already computed parameters, the values for *Input datum* do not need to be entered, but one should, of course, know which datum it is dealt with – the files associated with this program package GF_HOMP.TP; GF_AUTB.TP; GF_ZUPAN.TP; GF_CRO2000.TP are foreseen for the coordinates in accordance with the ETRS'89 reference frame and the epoch 1989.0, because of their transformation into the HDKS. Unlike the first type of transformations, we use here the procedure of classical Helmert's spatial seven-parameter transformation of coordinates.
- For the transformation of coordinates within one and the same datum (only the epoch is measured differently) there are the values of changes entered (the model NNR_NUVEL1A) for the movement of geological plate, i.e. their annual rotation change around global Cartesian axes on the GRS80 reference ellipsoid. In Europe, and thus in Croatia, there are the data for Euro-Asian lithosphere plate used (EURA).

The coordinates of points can be defined as rectangular spatial Cartesian (XYZ) or ellipsoid (φ,λ,h) coordinates, with the later ones having the possibility to be given in DEG (decimal degrees), DMS (degrees, minutes, seconds) and GRAD (decimal grades/gon) units. Since in the formulas during the transfer from XYZ into the other three types there are the parameters of the given ellipsoid used (the large and the small semi-axis, flattening, eccentricities, etc.) one should pay attention to the position of ellipsoid in the program menu. It is possible to define the following ellipsoids: WGS84, GRS80, Bessel 1841 and arbitrary.

3.2 Functions of the program

- The menu *Račun novih transf. parametara (Computation of new trans. parameters)*: - is used for computing one's own transformation parameters (7-parameter Helmert's transformation) on the basis of two various ASCII lists of common coordinates in both systems – the results of computation can be also saved as a report in ASCII file, and the new-computed transformation parameters are saved under some title into a new or already existing file in the form *.TP
- The menu *Odabir spisa transf.parametara* (*Selection of the trans.parameter file):* - we use the selection of TP file in which there the transformation parameters place, and according to which some points will be transformed.
- The menu *Pregled spisa transf.parametara (Trans.parameter file overview)*: - it is used for monitoring the contents of TP file, possible editing of values of transformation parameters, and there is also a possibility to enter the transformation parameters under some other working name manually.
- The key *Naprijed (Forward)*: - it is used only for computation (transformation) of points
- The key *Povećaj (Enlarge)*: - it is used for comparing primarily entered coordinates with the computed ones (the so called split screen appears)
- The key *Print*: - it provides the printing of the results in a raw output ASCII form
- The key *Projekcija (Projection)*: - it serves for the conversion of coordinates into the cylindrical projection – the projection depends on the position of ellipsoid of the output datum at the initial program interface.

Definition of the transformation parameters is carried out through the initial interface (Fig. 3.1), where it is possible to select the following options:

1. Menu *Nadzor (Supervision)*
2. Submenu *Odabir spisa transf. parametara (Selection of the transf.parameters)*
3. Submenu *Ulazni ili Izlazni datum (Input or Output datum)*
4. The adequate TP file is selected in the dialogue window for the purpose of carrying out the transformation through it – in one TP file there can be more (up to 256) transformation parameters.

Computation of transformation parameters (Fig. 3.1) is carried out in the following steps:

1. Menu *Nadzor (Supervision)*
2. Submenu *Račun novih transformacijskhi parametara(Computation of new transformation parameters)*
3. Reference file is the list the coordinates of which are expressed in the coordinate system that the transformation will be derived from, i.e. for which the transformation will be valid for.
4. The result file is the list of points in the coordinate system that the coordinates will be transformed into with computed parameters.
5. The computed parameters are saved into the already existing or some new TP file under a certain working name(up to max. 10 signs)
6. The report on the transformation and residuals (deviations) at the points in the result system can also be saved in some ASCII file.

While defining the type for an individual list, it is necessary to adjust adequate values first for the shape of the given coordinated and for the ellipsoid on which they are given.

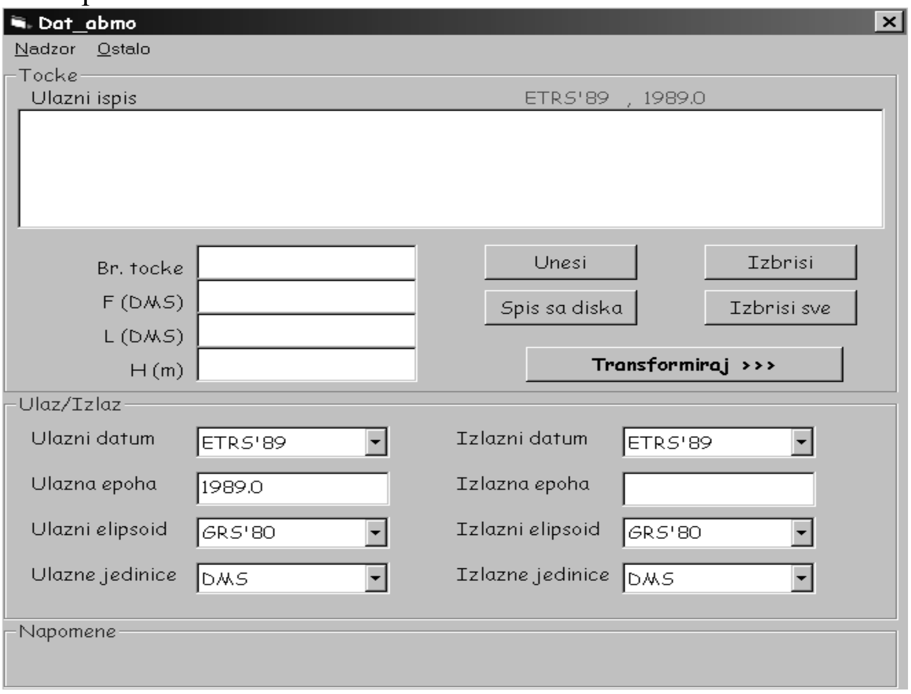

Fig. 3.1 Initial interface of DAT_ABMO program

Data formats

- INP file: ASCII list containing in its first row the data about the reference datum of the coordinates in the list, about the epoch of the points from the list, about the geological plate where the points belong to according to their location, and about the coordinate record type (the data can be spaced by the SPACE key), and not by the tab). For example, if we have in the first row: ITRF94 2001.3 2, it means that we deal here with the ITRF94 datum, 2001.3 epoch (the observations carried out in April 2001) and that the type of coordinate record is DEG (0=XYZ; 1=DMS; 2=DEG; 3=GRAD). After that we have classical ASCII list with names, coordinates and elevations of points.

- TP file: the file with a random access 90 bites long for each record (tX, tY, tZ, dM, rX, rY, rZ, vX, vY, vZ), i.e. 10 values of so called DOUBLE PRECISION accuracy (10×8=80) and IME as the title for specific structures of datum parameters of maximum 10 signs (10+80=90).

Additional files coming with the program:

- **GF_EUREF2001.TP**– official transformation parameters published in 2001 by EUREF, and computed by IERS service (International Earth Rotation Service)
- **GF_HOMP.TP**– transformation parameters of so called homogeneous fields at the territory of Croatia; computed at the Faculty of Geodesy in Zagreb
- **GF_AUTB.TP**– transformation parameters of the old Austro-Hungarian triangulation blocks; computed at the Faculty of Geodesy in Zagreb
- **GF_ZUPAN.TP**– transformation parameters of individual counties at the territory of Croatia; computed at the Faculty of Geodesy in Zagreb
- **GF_CRO2000.TP**– global transformation parameters for the Republic of Croatia published in IAG publication from the EUREF 2000 symposium in Tromso, Norway.

3.3 Registration of the program

It has been planned to carry out the registration of the program by electronic mail using the server in the State Geodetic Administration. When initiating the program, the registration interface appears if the program has not been registered yet (Fig. 3.2).

A user sends 'Serial number' of his/her application copy by electronic mail to the State Geodetic Administration and receives back as soon as possible the needed "Registration number" after identifying the user. This number is needed for further operation of the program (evaluation term is one week). If the program is deinstalled or one wishes to install it into another computer, the registration procedure must be repeated. When the program is regularly registered, the registration interface will appear at the moment of initiating the program. If the evaluation (test) term of one week expires, and the program has not been registered meanwhile, the program will not initiate any more.

The procedure is completely identical when registering IHRG2000 program.

Fig. 3.2. Registration form

4. Conclusion

Two utility programs IHRG2000 and DAT_ABMO, made in the Department for Geomatics at the Faculty of Geodesy, University of Zagreb to be used by the State Geodetic Administration of the Republic of Croatia should find their application in the practice, especially because the application of modern geodetic technologies requires that. Without knowing the accurate geoid surface it is impossible to make the connection between ellipsoid height that are today very accurately provided by GPS technology, and orthometric (≈altitudes) height that are used in practice. Without the transformations of coordinates between global and local datums, and among various epochs within the same datum, it is also impossible to process GPS measurements correctly, nor to present them in current geodetic reference system of our state (HDKS). The licensing system of the both programs by the State Geodetic Administration provides the uniqueness and official character for these computer programs, as well as for the data processed and realised using these programs.

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