Coordinate transformations for integrating map information in the new geocentric European system using Artificial Neuronal Networks

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Abstract: *The concept of "geodetic datum" was recently assimilated by geodetic specialized Romanian literature, and through it, we can operate in the more complex space of coordinate systems along with the reference surface specifications to which they relate. The necessary correspondence between local and global-geocentric data constitutes a current problem which is resolved under the accuracy terms, claimed in general by the terrestrial measurement works and in particular by the cadastral survey works. In this paper a new method for coordinates transformation is presented. The method consists of applying Artificial Neuronal Networks (ANN) in order to transform coordinates from those two geodetic datum that are presently used in our country.*

Keywords: *coordinates, system, network, neuronal*

1. Introduction

Romania's admission as a member with full rights into the European Union, event of historic importance, involves the adoption and/or elaboration of technical standards for the elaboration of digital cartographic outputs, which must fulfill the international standards concerning the codification, symbolism, manner of reference of data, storage of spatial information, creation and administration of a national GIS (Geographic Information System). This framework will enable the exchange between the European Community and international community and the creation of an infrastructure of National Spatial Data which will be compatible with the infrastructure for spatial information from Europe. These desideratum are possible and achievable by the adoption and fulfillment of the International Standard ISO 19111, adopted as a pan-European standard with the purpose of a precise and correct identification of the system of reference and of coordinates for each. The global positioning system (GPS) is frequently used in establishing geodetic networks because GPS provides location and time information with a high accuracy anywhere on the Earth.

In geodetic applications, the GPS techniques are widely used for determining three dimensional (3D) coordinates that is the base in surveying and mapping applications. The World Geodetic System 1984 (WGS84) is used for GPS measurements. To fully utilize WGS84, countries using different datum for their own coordinate basis have to make a datum transformation between their datum and WGS84 or change the datum to WGS84[8].

On May 29, 2009, under Order 212/2009, Romania has adopted the European Terrestrial Reference System ETRS 89. According to ISO 19111, ETRS 89 is made from ETRS 89 geodetic datum, based on GRS 80 ellipsoid and ellipsoid geodetic coordinate system.

The necessary correspondence between local and global-geocentric datum constitutes a current problem which is resolved under the accuracy terms, claimed in general by the terrestrial measurements works and in particular by the cadastral survey works.

Regarding the transition from local-national to European datum the solution implementations phase was successfully resolved (creating the permanent GNSS reference station network and coordinates transformations "Transdat" soft-A.N.C.P.I.). This procedure should be extended to other local reference systems such as those created for big cities and municipalities. This local systems served to create some small dimension local geodetic networks, which afterwards, formed the base on surveying the terrain details.

2. Theoretical review

The 3D coordinate transformation between ED50 and WGS84 can be performed by three steps of coordinate conversions: (1) Geographical to Cartesian; (2) Cartesian to Cartesian; (3) Cartesian to Geographical. The geographical (geodetic) coordinates must first be converted to Cartesian coordinates which is associated with the initial datum. These Cartesian coordinates are then transformed to Cartesian coordinates associated with desired datum. Finally, these transformed Cartesian coordinates are converted to geographical (geodetic) coordinates on the new datum [5].

The geodetic coordinates (φ, λ, h) can be converted to cartesian coordinates *(X,Y,Z)*

by:

$$X = (v+h)\cos(\varphi)\cos(\lambda) \tag{1}$$

$$Y = (v+h)\cos(\varphi)\sin(\lambda) \tag{2}$$

$$Z = \left[\left(1-e^2\right)v+h\right]\sin(\varphi) \tag{3}$$

where φ is the geodetic latitude, λ is the geodetic longitude and *h* is the ellipsoidal height. *v*

represents the radius of curvature in the prime vertical:

$$v = a/\left[1-e^2\sin^2(\varphi)\right]^{\frac{1}{2}} \tag{4}$$

where *a* and *e* denote the semi-major axis and first eccentricity of the reference ellipsoid.

The inverse conversion from Cartesian coordinates to geodetic coordinates is not straight forward and requires iteration. Several approaches have been developed for this reverse conversion, such as the non-iterative method by Bowring (1985), the iterative method by Borkowski (1989) and the vector method by Pollard (2002) [9]. The conversion from (X,

Y, Z) to (φ, λ, h) is given in Torge (2001) by:

$$\Phi = \tan^{-1}\left(\frac{Z}{\sqrt{X^2+Y^2}}\left(1-e^2\frac{v}{v+h}\right)^{-1}\right) \quad (5)$$

$$\lambda = \tan^{-1}\left(Y / X\right) \quad (6)$$

$$H = \sqrt{X^2+Y^2}\,\sec\varphi - v \quad (7)$$

When the geodetic coordinates have been converted to their Cartesian responses, the seven-parameter similarity transformation (Molodensky-Badekas) method and BPANN can be used to transform these Cartesian coordinates between K-40 and ETRS 89 for the evaluation process.

➢ Molodensky-Badekas

The conditions for an efficient 3D coordinate transformation are uniqueness, simplicity and rigor. Fast running, easy performing and highest accuracy can be accepted as criteria for an optimum 3D coordinate transformation method. The seven-parameter similarity transformation is widely used for 3D coordinate transformation in geodesy. The angles are not changed but the position of points may be changed in the seven-parameter similarity transformation. The seven-parameter similarity transformation has three translations of the coordinate origin, one scale factor and three rotation parameters. The 3D coordinates can be transformed into another reference frame by translating the origin, applying rotation in each axis and adjusting the scale. Three common points from two different coordinate systems are enough to estimate those seven transformation parameters, but more common points are used in a least squares adjustment to achieve ~~the~~ high precision.

The Bursa-Wolf (Bursa, 1962; Wolf, 1963) and Molodensky-Badekas (Molodensky et al., 1962; Badekas, 1969) are the most commonly used methods among seven-parameter similarity transformation methods because of their simplicity for application. Theoretically, the Bursa-Wolf and Molodensky-Badekas models should give the same results when the same data set are used.

The only conceptual difference between these models is the choice of the point about which the axial rotations and scale factor are applied [5]. Molodensky-Badekas method removes the high correlation between transformation parameters by relating the parameters to the centroid of the network. For this reason, Molodensky-Badekas method is used for this study.

The Molodensky-Badekas method is a seven parameter conformal transformation of 3D Cartesian coordinates between datum but is more suited to the transformation between terrestrial and satellite datum[9]. This transformation method comprises three shift parameters (D*X,* D*Y,* D*Z*) from the centroid of the terrestrial network (*Xm, Ym, Zm*), three rotation parameters (*RX, RY, RZ*) and a scale change (*dS*). The Molodensky-Badekas method is as follows:

$$\begin{bmatrix} X_{KA} \\ Y_{KA} \\ Z_{KA} \end{bmatrix} = \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} + \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} + \begin{bmatrix} 1+\Delta L & R_z & -R_y \\ -R_z & 1+\Delta L & R_x \\ R_z & -R_y & 1+\Delta L \end{bmatrix} \begin{bmatrix} X_{WGS}-X_m \\ Y_{WGS}-Y_m \\ Z_{WGS}-Z_m \end{bmatrix} \quad (8)$$

➢ Conformal linear transformation in 2D space

This transformation keeps only the topographic conditions and use the simplified hypothesis of one system translation and rotation in the same space from the other .

The correction equations are written matrix form:

$$B_{2n,4}X_{4.1} + L_{2n,1} = V_{2n,1} \tag{9}$$

$$\text{where: } B_{2n,4} = \begin{pmatrix} x_1 & -y_1 & 1 & 0 \\ y_1 & x_1 & 0 & 1 \\ x_2 & -y_2 & 1 & 0 \\ y_2 & x_2 & 0 & 1 \\ .. & .. & .. & .. \\ x_n & -y_n & 1 & 0 \\ y_n & x_n & 0 & 1 \end{pmatrix}; X_{4,1} = \begin{pmatrix} a \\ b \\ \Delta x \\ \Delta y \end{pmatrix}; L_{2n,1} = \begin{pmatrix} -X_1 \\ -Y_1 \\ -X_2 \\ -Y \\ .. \\ -X_n \\ -Y_n \end{pmatrix}; V_{2n,1} = \begin{pmatrix} v_{x_1} \\ v_{y_1} \\ v_{x_2} \\ v_{y_2} \\ .. \\ v_{x_n} \\ v_{y_n} \end{pmatrix} \tag{10}$$

where **n** is the number of double points with known coordinates in both systems.

3. The transformations coordinates possibilities between geodetic datum using ANNs

Cartographic projection used in "Iasi-local "coordinate system is a stereographical tangent projection which is characterized by the property of conformity , in which linear deformations are null in the central point and then increase, in small value, under a centimeter, for a radius of at least 30 km from the central. This is an important aspect regarding the process of reducing distances via the project plan. From one point of view this phase could be overlooked due to the precision lesser intake in the coordinates transformation. The projection central point is Golia Tower, having *Xo* = 10 000,000 m ; *Yo* = 10 000,000 m plane rectangular coordinates. The axes are orientated differently compared to Stereo-70 national projection, with the X on the East and the Y on the north along the place meridian [10].

For the coordinates transformation between the local system the global one it is necessary first to specify the magnitude order of the trans-calculus precision, as imposed by the purpose of such ~~a~~ works. Taking in consideration the primordial significant of cadastre information, in the first phase of research we can exclude the vertical Z component of the points, so that a two-dimensional transformation (2D) should be enough with no need for a three dimensional one (3D). This hypothesis also has the advantage of eliminating the inherent errors introduced by not knowing precisely the quasigeoid anomalies to ellipsoid, as it is known that the official Romanian heights system, namely „Marea Neagra-1975" heights system, is a system of normal heights (Molodensky) which must be related to an ellipsoidal heights system.

For further application of 2D coordinate transformation models it is necessary to know the minimum number of points, according to the used model, which have plane rectangular coordinate in both local and global reference system. Data required for the coordinates in the European system (ETRS 89) have been obtained through GPS measurements campaigns conducted in 2005 with the creation of geospatial network of Iasi and then in 2010 with the network extending for the entire metropolitan area of Iasi [2].

3.1. Back propagation artificial neural network

- Neural networks have emerged as a field of study within AI and engineering via the collaborative efforts of engineers, physicists, mathematicians, computer scientists, and neuroscientists. Although the strands of research are many, there is a basic underlying focus on pattern recognition and pattern generation, embedded within an overall focus on network architectures. Many neural network methods can be viewed as generalizations of classical pattern-oriented techniques in statistics and the engineering areas of signal processing, system identification, optimization, and control theory. There are also ties to parallel processing, VLSI design, and numerical analysis.
- A neural network is first and foremost a graph, with patterns represented in terms of numerical values attached to the nodes of the graph and transformations between patterns achieved via simple message-passing algorithms. Certain of the nodes in the graph are generally distinguished as being *input* nodes or *output* nodes, and the graph as a whole can be viewed as a representation of a multivariate function linking inputs to outputs. Numerical values (*weights*) are attached to the links of the graph, parameterizing the input/output function and allowing it to be adjusted via a *learning algorithm*[6].
- Neural networks have been trained to perform complex functions in various fields of application including pattern recognition, identification, classification, speech, vision, and control systems. Back-propagation (BP) was created by generalizing the Widrow-Hoff learning rule to multiple-layer networks and nonlinear differentiable transfer functions. Input vectors and the corresponding target vectors are used to train a network until it can approximate a function, associate input vectors with specific output vectors, or classify input vectors in an appropriate way as defined by you. Networks with biases, a sigmoid layer, and a linear output layer are capable of approximating any function with a finite number of discontinuities [7].
- ANNs are simplified models of decision-making processes of a human brain and are formed by interconnected artificial neurons or simply neurons. The input information of the neuron is manipulated by means of synaptic weights that are adjusted during a training process. After the training procedure, an activation function is applied to all neurons for generating the output information [9].

The multilayer perceptron (MLP) model was selected for this study because MLPs have ability to learn, operate fast, require small training sets and can be implemented simply among several kinds of ANN models. MLP consists of one input layer with N inputs, one hidden layer with q units and one output layer with n outputs. The output of the model (y) with a single output neuron can be represented by:

$$y = f\left(\sum_{j=1}^{q} W_j f\left(\sum_{l=1}^{N} w_{j,l} x_l\right)\right) \tag{11}$$

where W is the weight between the hidden layer and the output layer, w is the weight between the input layer and the hidden layer, x is the input parameter. A sigmoid function is used as activation function for hidden and out layers that is defined by:

$$f(z) = 1/\left(1 + e^{-z}\right) \tag{12}$$

where z denotes the input information of the neuron.

Each neuron within a network collects information by means of all its input connections, fulfills a predefined mathematical operation and offers an output value. Neurons are linked by weighted connections, storing the information. By adjusting the weights, the neuronal network is able to learn.

The network contains I input neurons, J hidden neurons and K output neurons. The weights of the input layer and the hidden one, respectively the hidden layer and the output one are noted with $w = \{w_{ij}\}$, respectively $v = \{v_{jk}\}$.

Functions of activation the neurons in the hidden layer and in the output one are noted with $g(\cdot)$, $h(\cdot)$ respectively. Driving such a network is made by using a set of driving data which make use of M desired in - out pairs, under the following form [1]:

$$x^{(m)} = \{x_1^{(m)}, x_2^{(m)}, \ldots x_I^{(m)}\} \div d^{(m)} = \{d_1^{(m)}, d_2^{(m)}, \ldots d_K^{(m)}\},\ m = 1,\ldots,M \quad (13)$$

Consequently, for an approximation as correct as possible of the desired outputs $d^{(m)}$, through the real outputs $o^{(m)}$, it is to be applied an adjusting grid weights method using as a target function a valuation of the approximation errors with the total square deviation.:

$$APT = \sum_{m=1}^{M} \left\| d^{(m)} - o^{(m)} \right\|^2 = \sum_{m=1}^{M} \sum_{k=1}^{K} \left(d_k^{(m)} - o_k^{(m)} \right)^2 \quad (14)$$

➢ **BPANN** model was selected because it has been more widely applied in engineering among all other ANN applications. BPANN has a feed-forward and supervised learning structure which consists one input layer, one or more hidden layers and one output layer, as shown in Figure 1[8]. The delta rule based on squared error minimization is used for BPANN training procedure .The training process corresponds to an adjustment of the weights between the hidden layer and the output layer to the data set that is composed of the known input and output parameters. This iterative adjustment updates the weights in order to decrease the difference between the computed output and the actual given output of the neural network. The training procedure consists of feedforward and back-propagation steps. These steps continue over the training set for several thousand iterations until the network performance reaches an acceptable value.

For determining the performance of the neural network, the mean square error (MSE) can be used that is defined by:

$$MSE = \sum_{1}^{N} \left(y_{known} - y_{neuronal} \right)^2 / N^2 \quad (15)$$

where N is the number of the inputs, *yknown* denotes the known (target) output value and *yneural* denotes the network output value.

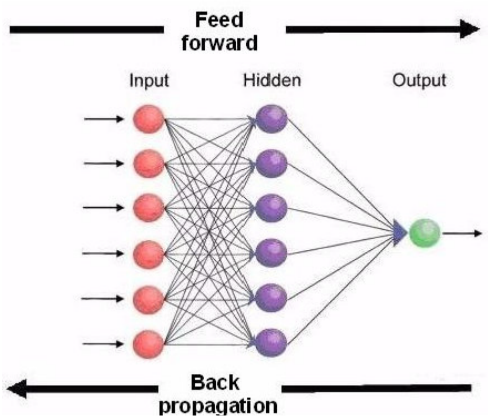

Fig.1. The general structure of a BPANN [9]

3.2. Aplication of ANN to 2D coordinate transformation

An artificial neural network can also be applied to cadastral coordinate transformation. Suppose there are n reference points in a specific region. The reference points set $P = \{P_1, P_2, ..., P_n\}$ can be used to train the BP artificial neural network (ANN) [7].

$$P_i = \left[\left(X_a, Y_a\right)_i, \left(X_b, Y_b\right)_i \right], 1 = 1, 2, ..., n \qquad (16)$$

where $\left(X_a, Y_a\right)$, $\left(X_b, Y_b\right)$ are the coordinate so of two reference point in both datum and i indicates the reference point number.

It should be noted that a three-layer BP ANN, with one input layer, one hidden layer, and one output layer, was adopted in this paper to transform coordinates from two diferent datum.

After being trained by the reference point set $P = \{P_1, P_2, ..., P_n\}$, the BP ANN establishes the functional relationship between the input layer$\left(X_a, Y_a\right)$ and the output layer$\left(X_b, Y_b\right)$:

$$\begin{matrix} \left(Y_b\right)_i = F\left[\left(X_a, Y_a\right)_i\right] \\ \left(X_a\right)_i = G\left[\left(X_a, Y_a\right)_i\right] \end{matrix}, \text{ i=1, 2, …, n.} \qquad (17)$$

where F and G are functions, which associate input vectors $\left(X_a, Y_a\right)_i$ with specific output vectors $\left(X_b, Y_b\right)_i$.

The functions of F and G are described implicitly in the hidden layer of the BP ANN. Hence, if the BP ANN has been trained, then the *a point* coordinates can be estimated by entering their *b point* coordinates into the trained BP ANN. In other word, if one logs out of the BP ANN program, one has to train the BANN again with reference points.

4. Conclusions

- In order to test the proposed algorithms, a set of software must be developed and revised based on the above-mentioned concepts. The artificial neural network program can be developed using the MATLAB artificial neural network toolbox. A 3-layer BP neural network, with one input layer, one hidden layer, and one output layer, should be adopted to establish the functional relationship between the coordinates of tje referenec points in both datum. The transfer functions for the hidden layer and the output layer are 'tansig' (hyperbolic tangent sigmoid transfer function) and 'purelin' (linear transfer function) respectively [4].

- For testing the accuracies of the proposed algorithms, some points must be used to train the artificial neural network, and others to evaluate the performance of the proposed algorithms. The points used to train the artificial neural network will be defined as reference points, while the other points which will be used to evaluate the performance of the proposed algorithms will be defined as check points.
- In order to study the 2D coordinate transformation, algorithms of applying a back-propagation artificial neural network (BPANN) is proposed.
- The Cartesian coordinates can transformed with a better accuracy by BPANN than Molodensky-Badekas for 3D coordinate transformation. The employment of a BPANN that is properly structured and trained can be an alternative tool in 3D coordinate transformation. With geographical coverage, more accurate 3D coordinate transformations can be expected from BPANN and also Molodensky-Badekas.

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