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On the Evaluation of the Neural Network Khartoum Geoid Model

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Abstract: This study was carried out to establish and evaluate an Artificial Neural Networks (ANN) geoid model for the Khartoum State. In the first stage the geometrical geoid heights were obtained from the differences between observed ellipsoidal heights and known orthometric heights of 48 geodetic Ground Control Points (GCP) in the study area. This followed by generating an ANN geoid model to extract the geoid heights from 42 ground control stations in the same study area in the Khartoum State. The main objective of this research study is to apply an ANN to model the Geoid surface using the back propagation algorithm in Khartoum state, through supervised training by geoidal undulations values. The WGS84 GPS/levelling geoid is computed then their results were used for comparison and evaluation of the determined ANN Geoid surface. In this study the geometrical geoid model was determined using the well-known geometrical geoid determination approach taking consideration of the distribution of the existing vertical control points in Khartoum area, with an intention of determining the orthometric heights of any point of unknown heights with uncertainties of less than 5cm. The ANN geoid uncertainties were evaluated and tested at 6 geodetic ground control points. The average difference between the derived geoid heights obtained from the geometrical geoid model, and their corresponding ANN geoid heights was found to be in the range of ±3 cm. Based on the test results of the statistical analysis and the study of a trained artificial neural networks model, the authors were able to estimate the geoid model with acceptable accuracy and can interactively be available for end users. This study showed that, the geoid heights in Khartoum State can be determined with the ANN method with typical accuracy of better than 5cm.

Keywords: GPS, GNSS, Geoid, WGS84, UTM, Ellipsoidal Heights, Orthometric Heights

1. Introduction

The Department of Surveying Engineering of the University of Khartoum, started to perform the determination of Khartoum local WGS84 geoid to cover the entire Khartoum State and aiming to proceed for deriving the local geoid model to cover the entire Sudan territory. By using the GNSS observations to obtain WGS 84 coordinates of all ground control points used in this study where their corresponding first order levelling orthometric heights are available. The geometrical geoid heights were computed from the differences between the ellipsoidal heights and orthometric heights at each point, i.e. this can be computed by difference between geodetic height, h (measured by GNSS) to obtain the geoid undulation by using the equation (H=h-N). This relationship was found to be different and unstable from one point to other. In recent years, Artificial Intelligence proved to be useful towards finding solution for such problems. Artificial Neural Networks (ANN) as inference engine for Intelligent Applications has been used in different field including Surveying. The advantage of the computation models of (ANN) which is based on various experiences proved to be valuable for the derivation of geoid heights.

The main objective of this study is to apply an ANN to model the Geoid surface using the back propagation algorithm in Khartoum state, through supervised training by geoidal undulations values. Based on the test results of the statistical analysis and the study of a trained artificial neural networks model, the authors were able to estimate the geoid model with acceptable accuracy and interactively be available for end users. The WGS84 GPS/levelling geoid is computed then their results were used for comparison and evaluation of the determined ANN Geoid surface.

Figure 1. *The study area- Khartoum State – Sudan.*

Khartoum State was considered to be the study area, the area is relatively flat surface with slight slope towards to the Nile, at elevation of about 385 m above mean sea level. The state lies between longitudes 31° 37′ 11" to 34° 23′ 8" E and latitudes 15° 10′ 54" to 16° 38′ 54" N. Khartoum State is surrounded by Northern State in the North West, in the West by North Kurdufan, in the East and South East by Kassala State and Gedaref, Gezira and White Nile State are in the south, and River Nile State in the North East. (Figure 1).

The data used in this study was obtained from the General Directorate of Survey (GDS) of Khartoum state, and based on their ongoing cooperation and collaboration with the Department of Surveying Engineering in all geomatics aspects. The data was in a form of geodetic UTM coordinates, Easting, Northing, and geographic latitude, longitude, ellipsoidal and orthometric heights. For the modeling by ANNs, the standard division of the discrepancies were computed and evaluated.

ANN Modelling Step followed in this study work is based in applying the ANN to model the Geoid surface by using the back propagation algorithm through supervised training,

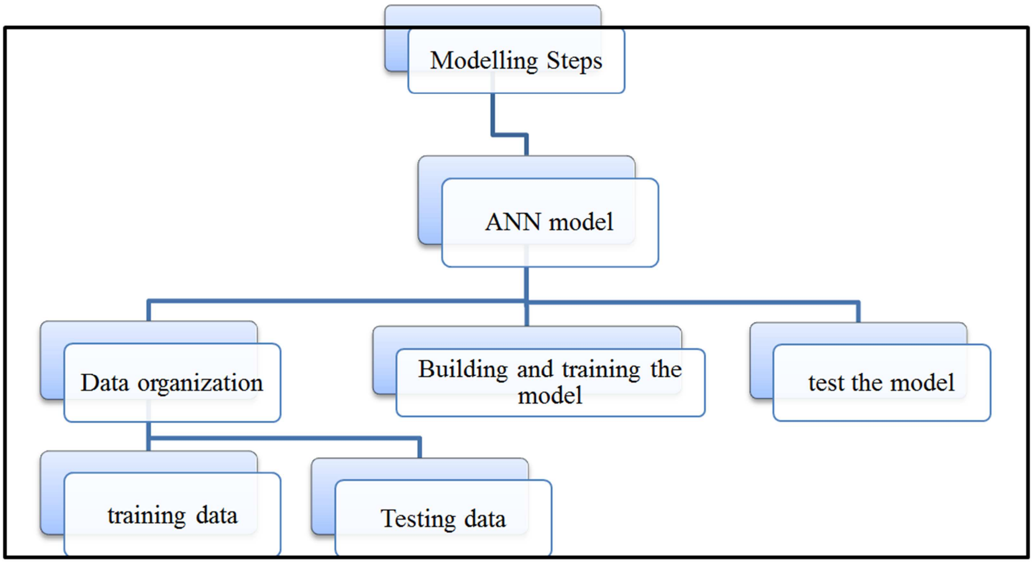

Figure 2. *Showed ANN Modelling Steps.*

The current height network in Khartoum State is based mainly upon a series of leveling runs carried out by the General Directorate of Survey (GDS) of Khartoum State in 2008. The accuracy was specified as 3 mm per square root of levelling run in kilometres. The aim was to provide one point for every 4 km². The datum used for this levelling was the Alexandria vertical datum. From the previous analysis of vertical control, it can be strategically stated that, in the future, the transformation from Alexandria to Port Sudan vertical datum may become essential, as the Country intended to move to use ITRF2008-WGS84 as a unified geocentric datum or reference frame/system for national geomatics and geospatial activities as well as to comply with the regional intention for the unification of African reference system and geoid. As well known, the ellipsoidal heights are not usually used directly for practical surveying and engineering as they have no physical meaning [7, 14]. Due to the current effective use of GNSS technology, it will be essential and cost effective to derive the orthometric heights from GNSS ellipsoidal heights through the implementation of ANN geoid modelling.

In Sudan, orthometric heights are assumed to be referred to Alexandria vertical datum, but the coincidence of this vertical datum with the geoid surface needs further investigation. There are many approaches to transform ellipsoidal heights to orthometric heights, such as by using gravimetric methods, global and geometrical methods. In this paper, only the ANN geoid model, was considered. Ellipsoidal and orthometric heights are given at 48 benchmarks to provide the geoid undulations at these common points.

2. Geometric Geoid Determination

In Sudan, most commonly known and used vertical datums are Alexandria and Sudan irrigation datums. Each system has separate observation and computation procedures, data availability, accuracy requirements, compatibility with GNSS, and the topographic settings in which the heights are used. Unfortunately even the relationship between these two datums is not well investigated, but in general the difference between the two datums was found to be about 3 metres.

Orthometric heights are referenced to an equipotential reference surface or the geoid [15], that approximating the mean sea level. The orthometric height, H, of a point on the earth's surface is the distance from a point measured along the plumb line and vertical to geoid. While the ellipsoidal height, h, are referenced to reference ellipsoid; and usually defined as the distance from the point at the earth surface to the reference ellipsoid, measured along the line which is perpendicular to the ellipsoid. At the same point on the surface of the earth the difference between an ellipsoid height levels and orthometric height is defined as the geoid height, N [1], and approximated in equation (1).

$$N = h - H \tag{1}$$

In this study, errors that affect the accuracy of the orthometric heights, ellipsoidal heights and the geoid heights values are generally considered to be the same and common in the ANN geoid model. With regards to the data used in this study, all leveling benchmarks and previous horizontal control points were occupied by GNSS and their 3-D geodetic coordinates were determined. GNSS observed ellipsoidal heights minus observed orthometric heights were computed. The total number of 48 GPS/leveling benchmarks were measured. The measurements were performed using Trimble dual frequency receivers R8 and DNK3 precise levels. All 48 GPS/Levelling benchmarks coordinates were computed on the known geodetic reference stations, using at least one hour GPS observations in order to define them in the same system at the specific epoch. The combined use of global Navigation Satellite System (GNSS), leveling and the derived geoid is considered to be a key procedure in deriving and evaluating the Khartoum ANN geoid model. Although these three types of height information are considerably different in term of physical meaning, surface realization, approximations, methods of observational, accuracy; but since the geoid heights in the study area is generally in the range of ±3 m, which means the geoid and ellipsoid surfaces are very close, it can be stated that the relationship between the ellipsoidal heights and their corresponding orthometric heights given by [2, 6] and [11]. should fulfill the following geometrical relationship with reasonable acceptable accuracy:

$$h - H - Ng = 0 \tag{2}$$

Where h are ellipsoidal heights obtained from GPS observations, H are orthometric heights derived from leveling methods and Ng are the geoid heights. In practice equation (2) is never satisfied due to the random noise in values of H, h and Ng; from many sources such as inconsistencies of datum, systematic distortions; geodynamic effects, and other appropriations in the computation of ellipsoidal and geoid heights.

3. Artificial Neural Network Architecture

Artificial Neural Network architecture (ANN) includes defining the number of layers, the number of neurons in each layer, and the interconnection scheme between the neurons. Figure 3 shows neural network architecture for three layer network with fully connected neurons of different layers. Selection of number of layers is controlled by training algorithm. Some training algorithms may require only one layer while other may require a minimum of three layers. For instance, back propagation algorithm requires an input layer, a hidden layer, and an output layer.

The number of hidden layers is selected based upon the problem complexity. The number of neurons in input and output layer is the problem specific. The inter connections between neurons are controlled by the training algorithm and the nature of the problem [11].

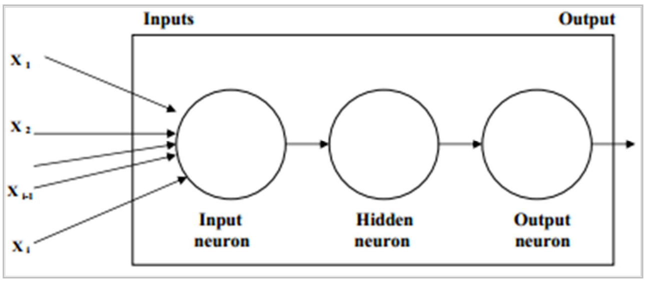

Figure 3. *Neural network architecture for three layer network.*

Artificial Neural Networks are broadly classified into (Back-Propagation Learning Algorithm, the Perceptron, the Adaline, Hebbian learning rule, and many other). In this paper the back propagation is used because it has ability to deal with non-linearity surfaces such as the geoid surface, it is a good learning algorithm to deal with geoid. Back-propagation is one of the most widely used supervised training algorithms [4, 8, 11, 14, 15].

The back propagation training algorithm uses gradient descent procedure to locate the absolute (or global) minimum of the error surface. In back-propagation, there are two phases in its learning cycle- firstly to propagate the input pattern through the network and secondly, to adopt the output by changing the weights in the network. It is the error signals that are back-propagated in the network operation to the hidden layer (s). The error in the output layers is used as a basis for adjustment of connection weights between the input and hidden layers. The adjustment of connection weights between the input and the hidden layers and subsequent recalculation of the output values become an iterative process which is carried out until the error falls below a tolerance level. A momentum parameter can be used in scaling the adjustment from a previous iteration and adding to the adjustments in the current iteration.

Before starting the training process, the weights in the network are initially set to small random values. This is synonymous with selecting a random point on the error surface. The back-propagation algorithm then calculates the local gradient of the error surface and changes the weights in the direction of steepest local gradient.

The back-propagation training process starts by inputting training data set to the network. The training data set consists of input and output vectors. When these vectors sequentially presented to the neural network, the following calculations are performed [7, 8, 11],

$$Z_j = \sum W_{ij}\left(X_i + B_j\right) \; i = 1,2,3 \ldots\ldots N \; j = 1,2 \ldots\ldots H \quad (3)$$

Where Z_i = input to the jth hidden layer neuron.

X_i = numerical value of the ith input vector.

W_{ij} = weight of the ith input layer neuron to the jth hidden layer neuron.

N = number of input layer neurons.

H = number of hidden layer neurons.

B_j = bias value for the jth hidden layer neuron.

The output of hidden layer using sigmoid function is calculated as follows.

$$h_j = f\left(Z_j\right) = \frac{1}{(1+e^{-Z_j})} \; j = 1,2 \ldots\ldots\ldots . H \quad (4)$$

Where, h_j = output of the hidden layer neuron j, f = transfer function for the hidden layer.

For training an Artificial Neural Network there are two approaches to training supervised and unsupervised, as in this study supervised training was adopted. In the training process, the network output, in general, may not be equal to the desired output. Consequently, the output error is calculated as the difference between the network output and the desired output. If the output error does not achieve the tolerance level, the network modifies the connection weights according to the value of the output error; then, training data are inputted again to the network and the network output is calculated. The training cycle is continued until the network achieves the desired tolerance level. If the error value is within the tolerance limit, the network becomes a 'trained' network. Thus, the back-propagation algorithm is summarized into seven steps:

i. Initialize the network weights,
ii. Present the first input vector, from the training data, to the network.
iii. Propagate the input vector through the network to obtain an output.
iv. Calculate an error signal by computing actual output to the desired (target) output.
v. Propagate error signal back through the network.
vi. Adjust weights to minimize the overall error.
vii. Repeat steps (ii) to (vii) with next input vector, until overall error is satisfactorily small.

The above implementation of the back-propagation algorithm is known as online training, whereby, the network weights are adopted after each pattern has been presented. Once a network has been structured for a particular application, that network is ready to be trained. To start this process the initial weights are chosen randomly, then, the training, or learning, begins.

4. Results and Analysis

Table 1 shows the results of the processing for test data. The differences between the accurate geometric heights obtained from GNSS observations and orthometric heights determination from levelling or gravimetric geoid determination, $N_{(known)}$ can be used for the assessment of ANN geoid ($N_{(ANN)}$) determination.

The first column shows the test points IDs; the second the geometrical geoidal undulation, the third the geoidal undulation obtained by ANN and the fourth column shows the differences between the geometrical geoid $N_{(known)}$ and $N_{(ANN)}$. The model of ANN is compared with Geometrical geoid Heights by using many points located inside and outside of the area of the training data to check the accuracy obtained (Table 1).

Table 1. *Discrepancies of ANNs geoidal undulations (in m).*

Points	$N_{(known)}$ (m)	$N_{(ANN)}$(m)	$\Delta N_{(ANN)}$ (m)
1	2.578	2.5774	0.0006
2	2.4167	2.442	-0.0253
3	2.4815	2.501	-0.0195
4	2.6322	2.6442	-0.012
5	2.517	2.5359	-0.0189
6	2.451	2.4427	0.0083

In comparing the results obtained in previous studies [3, 4] and [5], of different geoid determination techniques and methods, the RMS was found to be in the range of 1.215 cm [9, 10, 12, 13].

Analyzing the test results listed in Table 1, based on the BP neural network test results of the statistical analysis and the study trained Artificial Neural Networks model; in which ANN model has been able to estimate geoid heights in order of ±3 cm level and the mean square error of the study group (48 GCPs) and the test group of (42 GCPs) are found to be in the range of ± 1.3cm.

5. Conclusions

The determination of Orthometric heights is important for many tasks in engineering feasibility studies and design, mapping and geospatial activities. Geometrically, this can be determined by computing the difference between ellipsoidal height and geoid undulation. This relationship is different and unstable from one point to another. This study can be considered as an attempt to drive orthometric heights with accuracies of about 5cm from the ANN method. Investigation of the height system at Khartoum area, precise evaluation and analysis on the values of vertical control networks and benchmarks revealed that the ANN geoid heights can be used in engineering, mapping and many geospatial applications, especially in areas of densified geodetic network.

The Geoid surfaces at Khartoum state, are compared, based on the results and the statistical analysis carried out in this study. Considering the ANN method, the discrepancies at the test points was calculated to be in the range of ±3 cm. According to the test carried out in this study it could be concluded that, with the results found there is an expectation to generate Neural Network models for Geoid modeling with a level of accuracy better than 3cm.

References

[1] Abdalla, K. A (2003). Datum Transformation and Geoid Determination effects in the Quality of Geodetic Control in Developing Countries. Presented in XXIII General Assembly of the International Union of Geodesy and Geophysics, Sapporo, Japan, Nov. 2003.

[2] Abdalla, K. A (2006). Vertical Control Network of Al Ain Region. GIS development.net. Proceedings of Map Middle east 2006.

[3] Ahmed Zaki, Yasmeen Elberry, Hamad Al Ajami, Mostafa Rabah and Rasha Abd El Ghany (2022). Determination of Local geometric geoid model for Kuwait. Journal of Applied Geodesy. jag-July 2022-0017.

[4] Berkant Konakoglu and Alper Akar (2021). Geoid Undulation using ANNs (RBFNN and GRNN), multiple linear regression (MLR) and interpolation methods: A comparative Study. Earth Sciences Research Journal, Vol. 25, No. 4, December 2021, 371-382.

[5] Eleje Sylvester Okiemute (2021). Verification of the consistency of the proposed transformation of global geoid method accuracy for local geoid model of Nigeria Determination. FUDMA Journal of Sciences. FUDMA Journal of Sciences, vo;. 5 No. 4 December, 2021, pp. 49-55.

[6] Fashir, H. H., Salih, A. B. and Abdalla, K. A. (1989)."The Transformation between the Doppler Co-ordinate system and the geodetic Co-ordinate system in Sudan". Published in Australian Journal of Geodesy, Photogrammetry and Surveying, Australia.

[7] Featherstone, W. E, Denfith, M. C and Kirby, J. F (1998)). Strategies for the Accurate Determination of orthometric Heights from GPS. Survey review, 34, 267.

[8] Fyfe, C., 2000. Artificial neural networks and information theory. *University of Paisley*.

[9] Lars E. Sjöberg, Mohammad Bagherbandi (2017), Gravity Inversion and Integration Theory and Applications in Geodesy and Geophysics. Library of Congress Control Number: 2016963159, Springer International Publishing AG 2017

[10] Mirko Reguzzoni, Daniela Carrion, Carlo lapiege De Gaetani, Alberta AlBertella, Lorenzo Rossi, Glovanna Sona, Khulan Batsukh, Juan Fernando Toro Herrera,, Kirsten Elger, Riccardo barzaghi and Fernando Sanso (2021). Open Access to regional geoid Models: The International Service for the Geoid. Earth Syst. Sci data, 13, 1653-1666, 2021. Published by Copemicus Publications.

[11] Mukesh Khare (2007) *Artificial Neural Network in Vehicular Pollution Modelling*.

[12] Tata Herbert and Eleje Sylvester Okiemute (2021). Determination of orthometric heights of points using gravimetric/GPS and geodetic levelling approaches. Indian Journal of Engineering, 18 (49), pp. 134-144. April 2021.

[13] Ugo Falchi, Claudio Parente, Giuseppina Prezioso (2018). Global geoid adjustment on local area for GIS applications using GNSS Perminant Station Coordinates. Published by Vilnius Gediminas Technology University, Vol 44 No. 3 (2018).

[14] Walker, J. M. (2015) *Artificial Neural Networks*. doi: 10.1007/978-1-4939-2239-0.

[15] Zilkoski, R, B and Earlson, E, E. (2005): Guidelines for Establishing GPS –Derived orthometric heights. National Geodetic Survey, Maryland 20910.