Modeling of time series of Earth crust velocity field in Azarbaijan using multilayer neural network with PSO training algorithm

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Abstract

The coordinates of the stations along with their velocity field and determination of the strain field are the most important parameters in determining the surface deformation of the shell. Preliminary estimation of the Earth's crust velocity field, especially in seismic areas and near faults, can provide valuable information on the geodynamic structure as well as how faults operate.

Different solutions can be offered to solve such a problem. Paying attention to the reliability of the solution, its accuracy and efficiency, how to do it and most importantly the discussion of time and cost can be important and fundamental factors in this work. The purpose of this paper is to use modern and accurate methods to estimate and determine the velocity field and displacement field as well as strain tensor parameters in 3D. Artificial neural network (ANN) method with particle mass optimization training (PSO) algorithm for spatial estimation of crustal velocity changes in Iran has been studied. GPS measurements of Central Alborz network stations have been used to evaluate the method.

The average relative error calculated in 4 test stations for the permanent base network in the VE component of the velocity field is %13, in the VN component of the velocity field is %10/10 and in the Vz component of the velocity field is %15.18 of the artificial neural networks. For Central Alborz network, these values have been set as 18.41, 5.45 and %21.20 for VE, VN and Vz components, respectively. The results of this study show the high capability and efficiency of artificial neural network method in spatial estimation of the Earth's crust velocity field in this region.

Keywords: Artificial Neural Network, crust velocity, Azarbaijan, GPS Observations

Introduction

points. Finding the value of a function outside of this range is called extrapolation, and similar methods are commonly used for both.Applications of this network include velocity determination, strain field, atmospheric condition research, crust modeling, subsidence determination and crust elevation. In this research, the aim is to estimate the speed of geodetic points in the geodynamic range of Iran and Alborz region. This range is located in latitude and longitude. 37main network stations were used to analyze the shell velocity field. The characteristics of the statistical data used for the target network are given in Table (1).

	V_x (mm/yr)	V_y (mm/yr)	V_z (mm/yr)
	-0/071	-0/0589	-0/06
Max	0/1984	0/4172	0/248
average	-0/0196	0/0152	0/0198
Standard deviation	0/0389	0/0696	0/0421

Figure (1) shows the spatial distribution of these 37stations. In this figure, the black triangle represents the stations used as the input of all three methods and the red circles represent the test stations. Out of 37stations, 4stations have been selected as test stations. The spatial distribution of these 4stations is such that it can provide a correct assessment of the accuracy of the results obtained from all three methods

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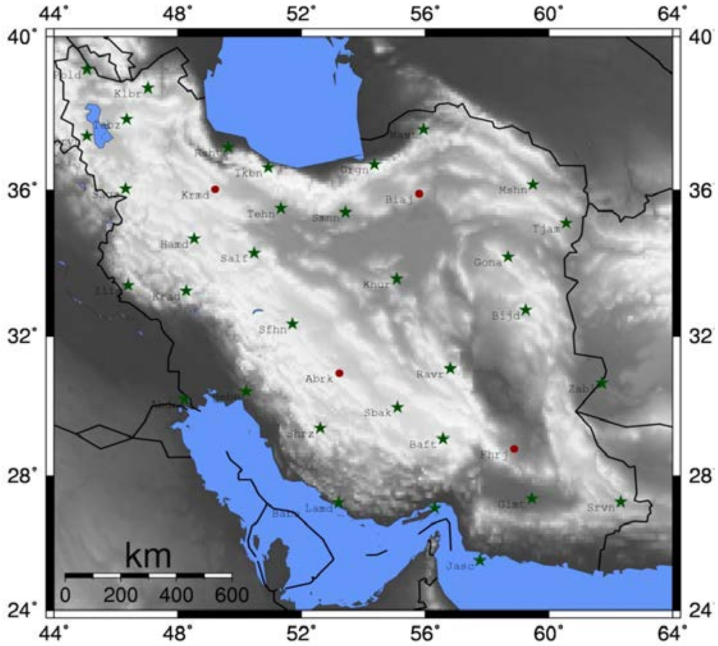

Fig.1.How to distribute the stations used in this research
(stars indicate the stations used as input to the methods, red circles indicate the test stations)

Processing observations

The coordinates of the stations along with their velocity field and determination of the strain field are the most important parameters in determining the surface deformation of the shell. Preliminary estimation of the Earth's crust velocity field, especially in seismic areas and near faults, can provide valuable information on the geodynamic structure as well as how faults operate. Figure (2) shows the velocity vectors in the Iranian region relative to the Eurasian plate with a %95 error ellipse (velocity vectors obtained by Berness v.4.2 software).

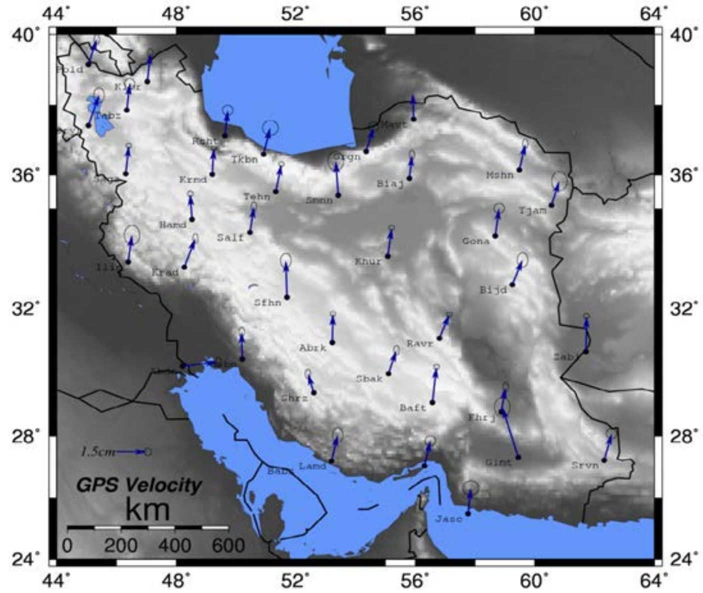

Fig.2. Crust velocity vectors in the region of Iran relative
to the Eurasian plate with an ellipse %95 error obtained from GPS processing

According to this figure, it can be seen that the velocity vectors presented are related to the location of geodynamic network stations. It is important to note that in the absence of a station from a geodynamic network in a particular area, such as near an active fault, it is necessary to use methods that can estimate the velocity field at those points.

The stations used in this research are divided into three groups: 30stations to train the network after error propagation, 3 stations to evaluate the network error and 4 stations to test the results obtained from the modeled artificial neural network.In this design, in order to use artificial multilayer perceptron neural networks and also to teach post-propagation error, an input layer, a hidden layer with sigmoid activation function and an output layer with linear activation function have been used. The key here is the number of hidden layer neurons.

The number of hidden neurons in multilayer neural networks will have a significant impact on the results. The number of these neurons is usually obtained by trial and error. Of course, it should be noted that the large number of hidden neurons in the hidden layer leads to the problem of excessive fit, and also the small number of hidden neurons will make the post-fault algorithm in network training difficult.

In neural networks, in order to obtain the optimal network structure, the input data are usually divided into three separate categories: training set, test set and evaluation set. In all three categories, the concept of mean square error is used to evaluate the error as follows

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$$MSE = \frac{1}{N}\sum\left(v_i^{Actual} - v_i^{\Pr edict}\right)^2 \quad (1):$$

In relation (1), v_i^{Actual} they represent the velocity values obtained from GPS and $v_i^{\Pr edict}$represent the velocity outputs determined from the neural network.

According to the analyzes performed in this study, a 3-layer neural network with 25neurons in the hidden layer has been identified as suitable for modeling the northern and eastern components of the Earth velocity field in Iran. It should be noted that in each input the problem is the geodetic coordinates of the points and the output of the velocity vector at the desired point. Figure (3) shows the velocity field met at other geodetic points on the Iranian plateau by means of an artificial neural network

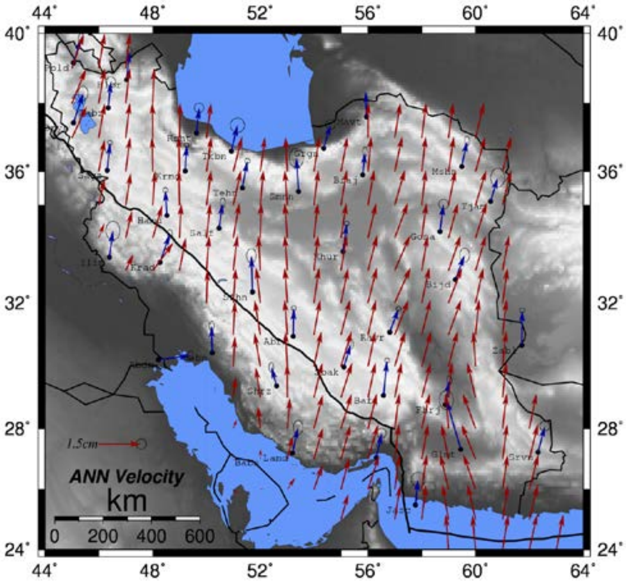

Fig.3. Estimated velocity vectors using a three-layer neural network relative to the Eurasian plane

Tables (2) and (3) show the relative speed and error values obtained from GPS and ANN models for the eastern and northern components at 4test stations.

Table 2: Speed and relative error values obtained from GPS, ANN models for Eastern component (VE) in 4test stations

Statation name	Latitude (deg)	Longitude (deg)	GPS Velocity (m/yr)	ANN. Velocity (m/yr)	Relative Error (%) (GPS- ANN)
Krmd	36.012	49.210	-0.0318	-0.027	10.83
Biaj	35.903	55.805	-0.02553	-0.027	14.70
Abrk	30.950	53.226	-0.02941	-0.025	8.73
Fhrj	28.774	58.881	-0.0427	-0.029	17.74

Table 3: Speed and relative error values obtained from GPS, ANN models for the northern component (VN) at 4 test stations

Statation name	Latitude (deg)	Longitude (deg)	GPS Velocity (m/yr)	ANN. Velocity (m/yr)	Relative Error (%) (GPS- ANN)
Krmd	36.012	49.210	-0.00198	0.002	17.00
Biaj	35.903	55.805	0.00967	0.016	1.51
Abrk	30.950	53.226	0.00057	0.003	4.16
Fhrj	28.774	58.881	-0.00897	0.013	17.75

According to the above figures and tables, it can be concluded that the results obtained from artificial neural networks in estimating the speed of geodetic points, both in direction and in a small amount, have a significant agreement with the results obtained from GPS processing. Table (4) shows the velocity field values obtained from GPS processing, the velocity values estimated by the artificial neural network, and the relative error values at the 4test stations

	Table 4: Values of speed fields obtained from processing and estimated speed fields from artificial neural network with relative errors in selected test stations in the desired network									
	ایستگاه	Speed field obtained from GPS (m / yr)			Estimated velocity field (m / yr)			Relative error (%)		
		V_E	V_N	V_z	V_E	V_N	V_z			
	Krmd	-0.0318	-0.00198	0.00961	-0.027	0.002	0.00842	10.83	17.00	12.38
	Biaj	-0.02553	0.00967	0.01612	-0.027	0.016	0.0201	14.70	1.51	24.69
	Abrk	-0.02941	0.00057	0.01618	-0.025	0.003	0.01842	8.73	4.16	13.84
	Fhrj	-0.0427	-0.00897	-0.00366	-0.029	0.013	-0.00402	17.74	17.75	9.84

Performance analysis in Azerbaijan network

In order to evaluate the full efficiency of the neural network model mentioned in this research, in estimating the speed of geodetic points in different regions, 22 stations of the local network of Azerbaijan were selected in this section and the values of the velocity field using the time series of GPS stations in this region by the organization. Country mapping is calculated. Figure (4) shows the values of the velocity field obtained for the Azerbaijan network.

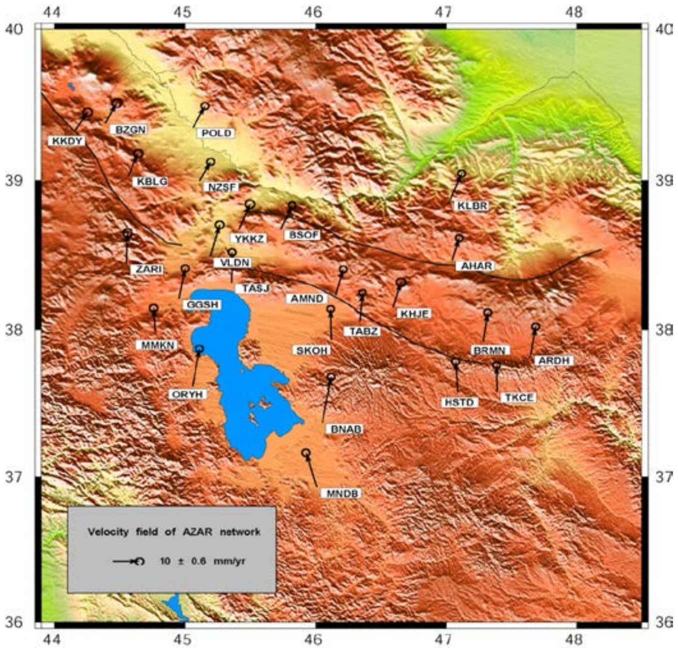

Fig.4.Speed vectors of Azerbaijan network
stations relative to the Eurasia plane taken from the site of the Iran Mapping Organization

In this section, the aim is to estimate the velocity of geodetic points in the geodynamic range of Iran (Azerbaijan region. This range is located in latitude and longitude. Figure (5) shows how the 22 stations of the Azerbaijan network are distributed

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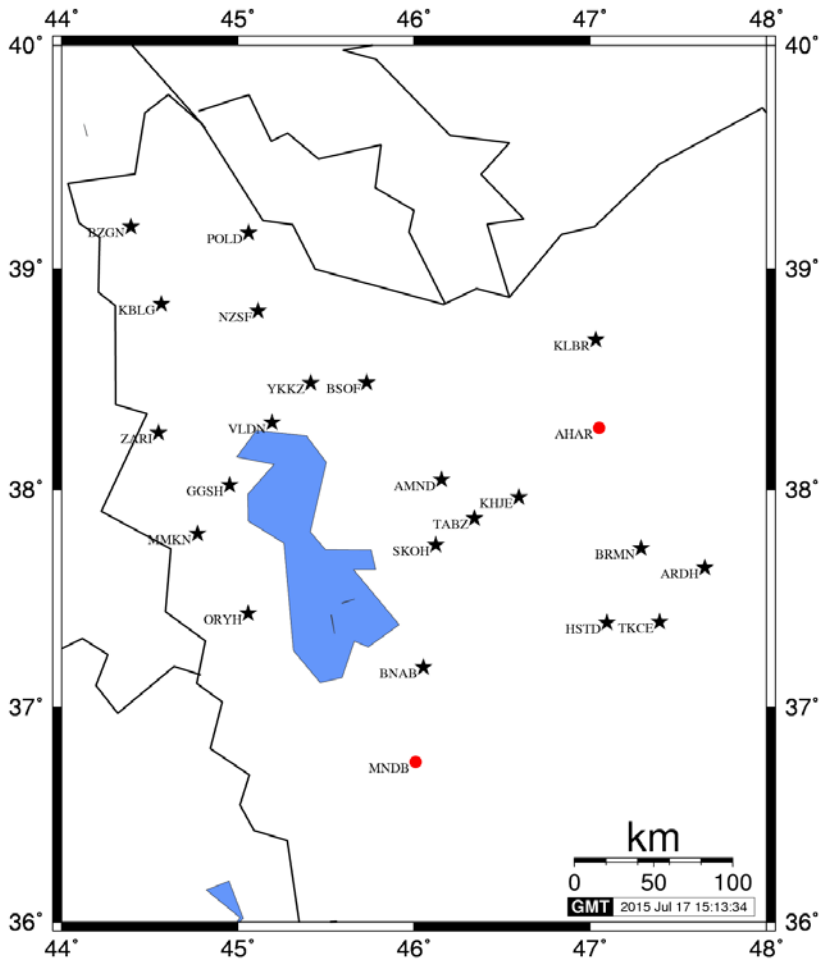

Fig.5. How to distribute the stations used
in the region of Azerbaijan (stars indicate
the stations used as input to the methods, red circles indicate the test stations(

The stations used in this network are divided into three groups: 16stations have been used to train the network after error propagation, 4stations have been used to evaluate the network error and 2stations have been used to test the results obtained from the modeled artificial neural network. The evaluation of the obtained results is compared with the velocity vectors obtained from GPS processing relative to the Eurasian plate. This evaluation is done as follows :

$$\Delta V_{E,N} = V_{(Known)} - V_{(Estimated)} \qquad (2)$$

In relation (2) $\Delta V_{E,N}$, the error values obtained for the estimated velocity vectors $V_{(Known)}$ are the velocity values obtained from GPS observations and $V_{(Estimated)}$ the estimated velocity values from the artificial neural network. Square root mean error is the best criterion for evaluating the error values obtained from artificial neural network modeling. This criterion is defined as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\Delta V_{i\,E,N}\right)^2} \qquad (3)$$

The geographical coordinates of each station in the target network are considered as the input of the artificial neural network and the velocity vectors obtained from the GPS observation processing are introduced as the output parameter for network training. In this research, two separate artificial neural networks have been used to estimate the velocity vectors of geodetic points. The number of hidden layer neurons in both networks is determined based on the square root mean square error criterion. It should be noted that a 3-layer neural network with 18neurons in a hidden layer has been used to model the northern and eastern components of the Earth velocity field in the northwestern region of Iran (Azerbaijan network). Figure (6) shows the velocity vectors obtained from GPS processing.

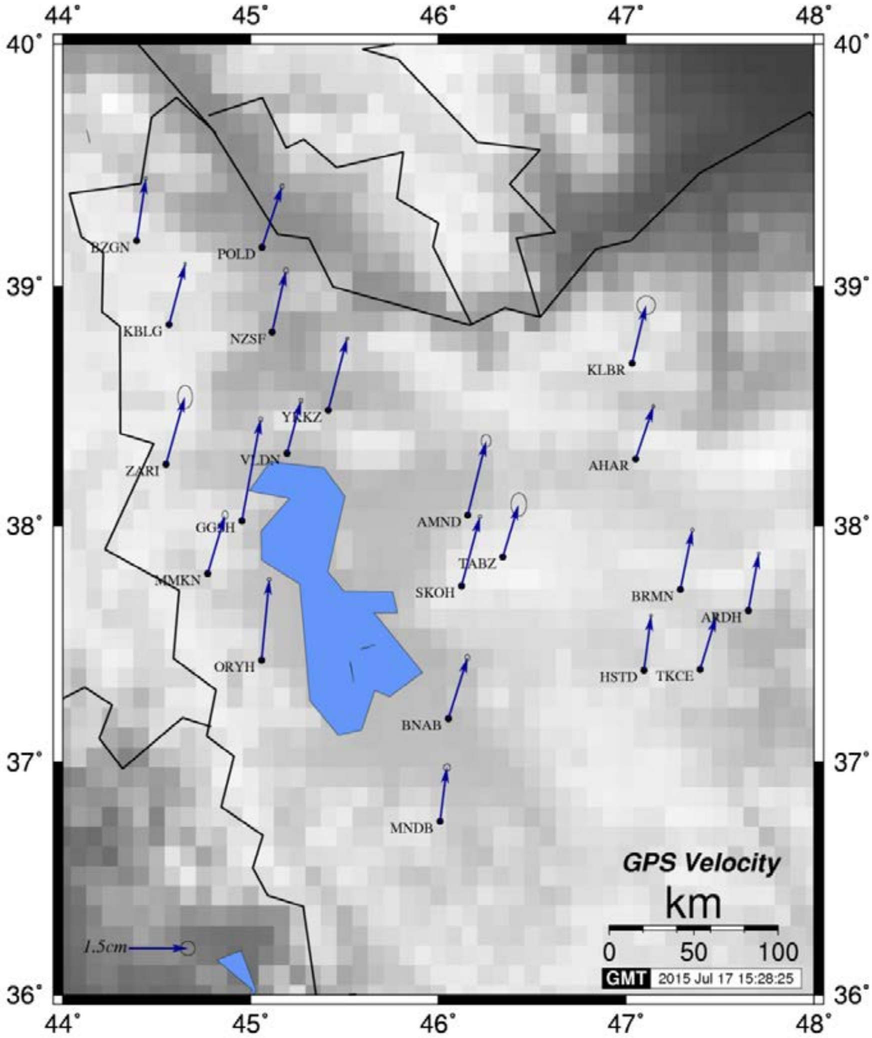

Figure 6: Speed vectors obtained from GPS data relative to the Eurasian plate

Figure (7) also shows the velocity field satisfied in other geodetic points in the region of Azerbaijan by the neural network method.

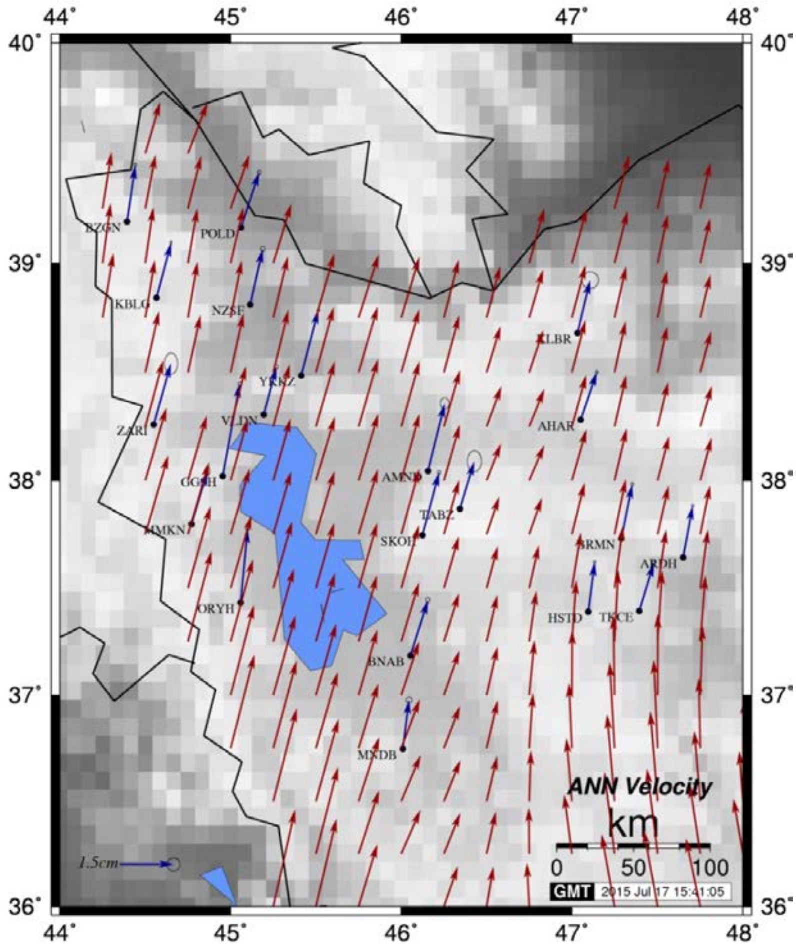

Fig.7. Estimated velocity vectors using
a three-layer neural network relative to the Eurasian plane

Tables (5) and (6) show the relative velocity and error values obtained from the GPS and ANN models for the eastern and northern components at the two test stations.

Table 5: Speed and relative error values obtained from GPS, ANN models for Eastern component (VE) in 2test stations					
Statation name	Latitude (deg)	Longitude (deg)	GPS Velocity (m/yr)	ANN. Velocity (m/yr)	Relative Error (%) (GPS- ANN)
Ahar	38.281	47.049	-0.0267	-0.0238	10.86
Mndb	36.745	46.009	-0.02736	-0.0291	-6.36

Table 6: Speed and relative error values obtained from GPS, ANN models for the northern component (VN) at 2test stations					
Statation name	Latitude (deg)	Longitude (deg)	GPS Velocity (m/yr)	ANN. Velocity (m/yr)	Relative Error (%) (GPS- ANN)
Ahar	38.281	47.049	0.00904	0.00803	11.17
Mndb	36.745	46.009	0.00343	0.00251	26.82

According to the results obtained in Tables (5) and (6), it can be concluded that the minimum relative error obtained from the artificial neural network is %6.36for the northern component and %11.17for the eastern component and the maximum value. The relative error is %10.86for the northern component and %26.82for the eastern component of the velocity field. Table (7) shows the 3D velocity field values obtained from GPS processing, the velocity values estimated by the artificial neural network, and the relative error values at the 2test stations
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Table 7: Values of speed fields obtained from processing and speed fields estimated from artificial neural network with relative errors in selected test stations in the desired network

ایستگاه	Speed field obtained from GPS (m / yr(			Estimated velocity field)m / yr(			Relative error (%)		
	V_E	V_N	V_z	V_E	V_N	V_z			
Ahar	-0.0267	0.00904	0.01381	-0.0238	0.00803	0.01687	10.86	11.17	22.16
Mndb	-0.02736	0.00343	0.0177	-0.0291	0.00251	0.0214	6.36	26.82	20.90

Discussion and Conclusion

One of the goals of geodesy is to calculate and determine the velocity field of the earth's crust, especially around active faults. By knowing the value and direction of the velocity field, an initial assessment of how faults operate can be obtained. The use of satellite geodetic network data is a general solution in determining the velocity field of geodetic points. The main problem with the use of satellite geodetic network data is the sometimes inadequate distribution and the small number of stations. This is especially true around active faults. To solve this problem, the use of appropriate and accurate interpolation methods that can accurately estimate the values of the velocity field in places without satellite geodetic network stations is necessary and inevitable. Therefore, in this paper, the efficiency and accuracy of velocity field estimation were evaluated by multi-layer artificial neural networks. The method was evaluated on three GPS networks in Iran. From the observations of 37stations from the Iranian geodynamic network, 22stations from the observations of the local network of Azerbaijan were used to test the results of the methods. In order to train and determine the model coefficients, the velocity field obtained from the GPS processing of the stations was used. In the first network, observations of 37stations were used, of which 4stations, 4stations were used to test the results of the method. In the second network of 22stations, 2 stations were used to test the results. The test stations in both networks were selected so that they were as far away from the main stations of the networks as possible in order to properly assess the accuracy and precision of the results obtained from the method. It should be noted that the speed fields of the test stations are not used in training calculations and coefficient determination.

In the neural network model, a 3-layer structure with 25neurons in the hidden layer was used to estimate the velocity field of the geodetic points. The number of hidden layer neurons was determined based on trial and error and based on the minimum relative error generated at the test points. With this structure, the average relative error produced at the test points was + 13.48for the northern component and + 18.12for the eastern component of the velocity field. The results indicate the relative superiority of the artificial neural network model in estimating the velocity field in the region of Iran. As a suggestion for future research, a suitable station distribution with a large number can be used to evaluate the efficiency of this method, especially near active faults.

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