Wind Speed Prediction Using Artificial Neural Networks

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ABSTRACT: A multilayered artificial neural network has been used for predicting the mean monthly wind speed in regions of Cyprus where data are not available. Data for the period 1986-1996 have been used to train a neural network, whereas data for the year 1997 were used for validation. Both learning and prediction were performed with adequate accuracy. Two network architectures of the similar type have been tried. One with eleven neurons in the input layer and one with five. The second one proved to be more accurate in predicting the mean wind speed. The maximum percentage difference for the validation set was confined to less than 1.8% on an annual basis, which is considered by the domain expert as adequate.

KEYWORDS: Wind speed prediction, artificial neural networks.

INTRODUCTION

The increased use of energy and the depletion of the fossil fuel reserves combined with the increase of the environmental pollution have encouraged the search for clean and pollution-free sources of energy. One of these is wind energy. This is a clean, inexhaustible and a “free” source of energy that has served the mankind for many centuries by propelling ships, driving wind turbines to grind grains and for pumping water. Despite the high cost of wind power this may become a major source of energy in the years to come. This is so because the severe pollution of the planet originating from the burning of the fossil fuels and the nuclear energy risks cannot continue forever.

The predicted variations of meteorological parameters such as wind speed, relative humidity, solar radiation, air temperature, etc. are needed in the renewable industry for design, performance analysis, and running cost estimation of these systems.

For proper and efficient utilisation of wind power, it is important to know the statistical characteristics, persistence, availability, diurnal variation, and prediction of wind speed. The wind characteristics are needed for site selection, performance prediction and planning of wind turbines. Of these characteristics, the prediction of mean monthly and daily wind speed is very important.

Mohamed *et al*., (1998) have used an artificial neural network (ANN) to predict the wind speed one hour ahead with very satisfactory results. Neural networks have been used before by the authors for the prediction of precipitation (Kalogirou *et al*., 1998a). In the present work ANNs are used to predict the mean monthly wind speed of a region in Cyprus, which is one of the best sites for installing wind turbines. The mean monthly wind speed is a representative figure of the wind potential of a site. Based on this figure one can decide whether a particular site has a good wind potential for wind energy applications.

In the following discussion X# and Y# means co-ordinate X and Y of station number #. Similarly, W# means mean monthly wind speed of station number #. The distance in meters quoted (i.e., 2m and 7m) determines the height of the anemometer at which the mean wind speed is measured.

DATA COLLECTION

The region is located at the south-eastern part of Cyprus as shown in Fig. 1. The topography of area is generally flat with an elevation ranging from 45 to 70m. Three meteorological stations are in operation in the region for a number of years. The observed data of wind in the three stations cover the years 1986-1997. Wind speed is measured at two levels 2m and 7m. All data are recorded and analysed by the Meteorological Service Department of the Ministry of Agriculture, Natural Resources and Environment. A sample of these data is shown in Table 1.

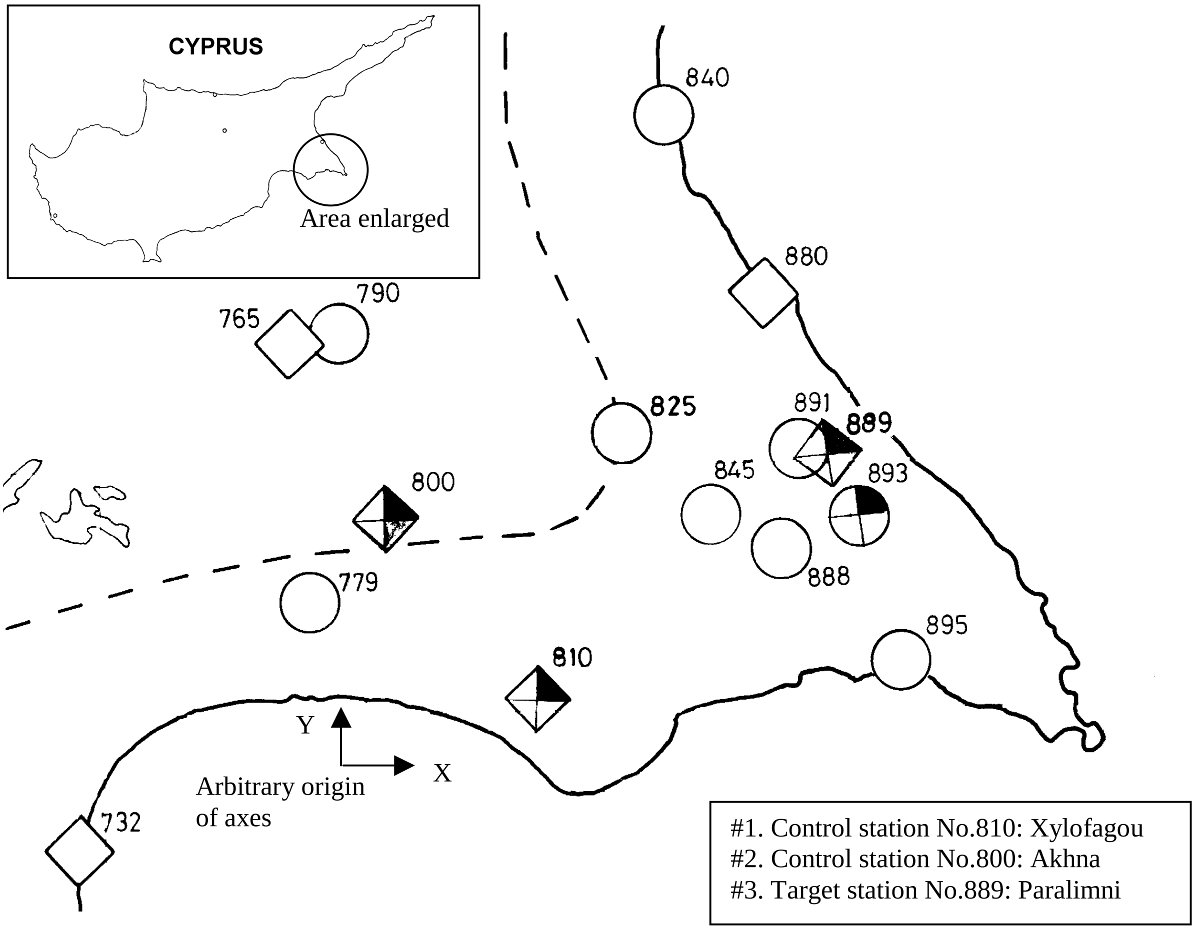

Figure 1. Map showing the location of meteorological stations.

METHODOLOGY

The database used was divided into two sets: A training data set having all wind speed records for each month for the years from 1986 to 1996 (i.e., 11years), and a verification data set for all months of 1997. The training data set has been used for the training and testing of the artificial neural network, while the verification data set has been used for validation of the network.

Different network structures, sizes and learning parameters have been tried. The architecture that was ultimately selected is shown in Fig. 2. It is composed of five slabs, three of which are hidden. This type of architecture has been used successfully for other engineering applications of neural networks (Kalogirou *et al.*, 1996; Kalogirou *et al.*, 1998b). The activation function used for each slab is also shown in this figure.

Originally, the input data comprised values of the co-ordinates of each station, as measured from an arbitrarily selected point (shown in Fig. 1) and wind data values collected at each station. These are, the month of the year, and the mean monthly values of wind speed at two levels (2m and 7m) for the two "control" stations (stations 1 and 2 in Fig. 1). The output of the network is the mean monthly values of wind speed of a third station called "target station" (station 3 in Fig. 1). Eleven input parameters were tabulated for each month of the year. After learning, the contribution of each input parameter was investigated. This is an extra feature of the package used. The contribution is a measure of the importance of that variable in predicting the network's output relative to the other input variables. This is shown graphically in Fig. 3 from where it can be seen that the co-ordinates contribute about one-third to the network output as compared to mean wind speed of each station. It was then decided to use only the mean wind speed of two stations at the two elevations (2m and 7m) as input parameters. For the second network the number of neurons in the hidden slabs were kept to six.

Table 1. Training data set-Sample.

Year	Month	Mean monthly wind speed (m/s) at height indicated					
		W1 at 2m	W1at 7m	W2 at 2m	W2 at 7m	W3 at 2m	W3 at 7m
1986	1	2.2	3.9	1.5	2.9	2.9	4.0
1986	2	1.5	3.1	1.2	2.5	2.2	3.1
1986	3	1.8	3.4	1.4	2.8	2.7	3.6
1986	4	2.3	3.9	1.7	3.3	2.9	3.7
1986	5	2.3	3.9	1.8	3.3	2.8	3.7
1986	6	2.3	4.0	2.0	3.5	2.9	3.6
1986	7	2.3	3.9	1.8	3.5	2.9	3.6
1986	8	2.2	3.8	1.8	3.4	2.8	3.4
1986	9	1.8	3.3	1.7	3.1	2.3	3.1
1986	10	1.6	3.3	1.6	2.9	2.2	3.2
1986	11	1.9	3.9	1.6	3.0	2.5	4.0
1986	12	2.1	4.2	1.8	3.2	2.3	3.6
1987	1	3.0	4.9	2.1	3.5	2.9	4.4
1987	2	2.6	4.6	1.7	3.1	2.9	4.5
...	...	...	...	...	...	...	...

Finally, five element inputs have been used corresponding to the values of the input parameters listed above (month, 2 x wind speed at 2m, 2 x wind speed at 7m) for the two stations. In both networks the learning procedure was implemented by using the backpropagation algorithm. Also, the learning rate was set to a constant value of 0.1 and the momentum factor to 0.9. The weights were initialised to a value of 0.3. From a total of 120 patterns, 90 percent were used for training the network (100 patterns) and the remaining 20 patterns were randomly selected to be used as test patterns.

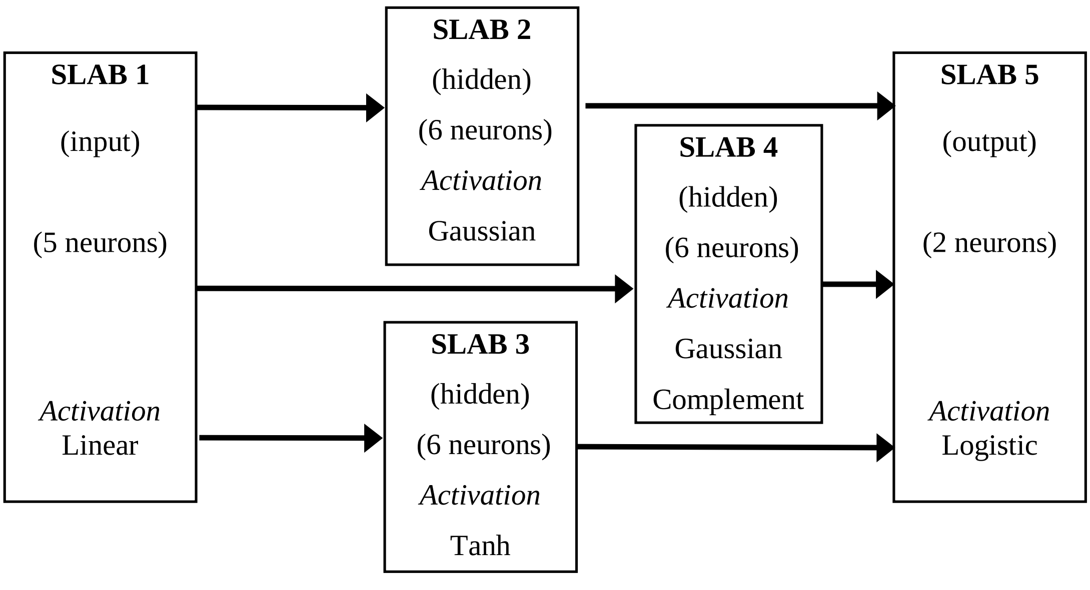

Figure 2. The selected neural network architecture.

RESULTS AND DISCUSSION

For an independent assessment of the network the results of the verification year 1997 are presented. The required data for this year are shown in Table 2. The results are shown graphically in Fig. 4 for the case where the co-ordinates were included in the input and in Fig. 5 where only the mean wind speed was used. The maximum error of the wind speed has been found to be 1.05 m/s for the first case and 0.32 m/s for the second. The observed and estimated wind speed patterns appear to display a quite satisfactory match. In particular, the seasonality of wind speed at the target station shown here is well simulated.

Table 2. Monthly mean wind speed for target station. Validation data set.

Year-Height	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997-2m	3.0	2.0	2.8	2.8	2.0	2.4	2.5	2.4	2.4	1.8	2.4	2.3
1997-7m	4.9	3.1	--*	4.4	3.2	3.5	3.6	3.5	3.6	3.0	3.7	3.7
* Missing data for this month												

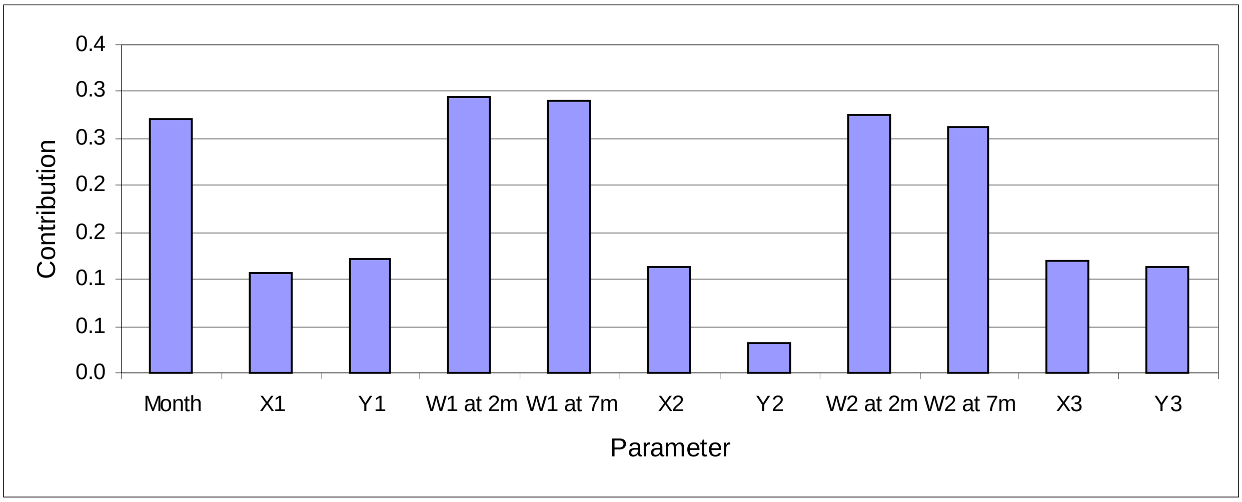

Figure 3. Relative contribution of the input parameters.

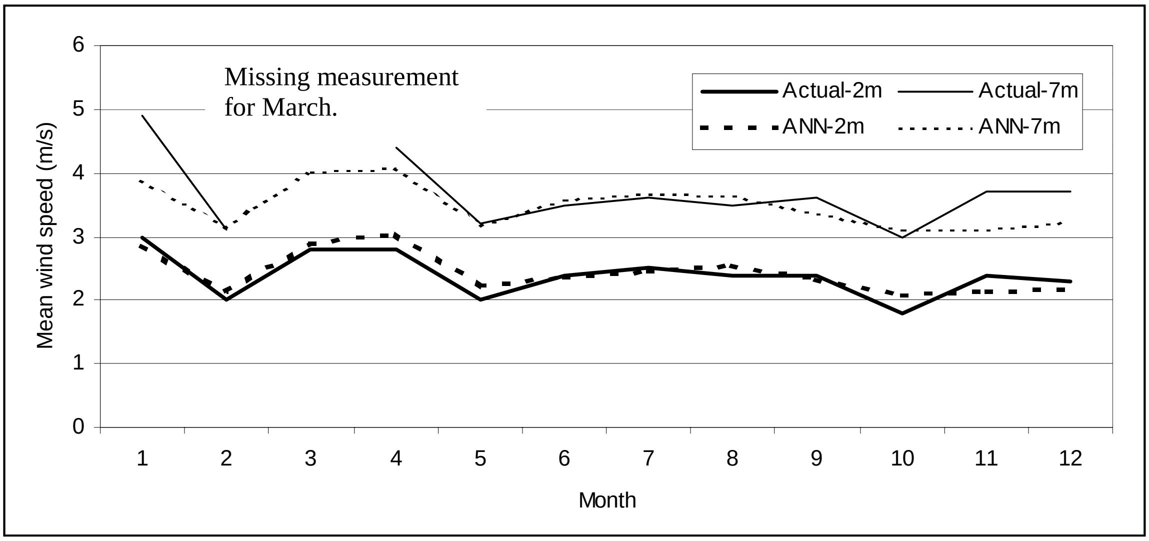

Figure 4. Mean wind speed for network using 11 input parameters.

It can also be observed from Figures 4 and 5 that one of the values from the actual data set is missing. This is due to faulty operation of the anemometer during most of the days in that month. A comparison of the mean wind speed at the two levels (2m and 7m) for the two networks is shown in Table 3. As can be seen from both Figures 4 and 5 and Table 3 the network using only 5 input parameters is more successful, giving a maximum percentage difference of only 1.8%. Therefore, the two networks can be used for two different types of jobs. The first network can be used more effectively in cases where the objective is to use the network to predict the wind speed in locations other than the three station locations. In this case the coordinates must be used as an input parameter. The target station (unknown station) can be located either within the area marked by the three stations (interpolation) or outside (extrapolation). The second network can be used to predict mean wind speed in fixed locations more successfully, therefore, it can be used to fill missing data values from the meteorological databases.

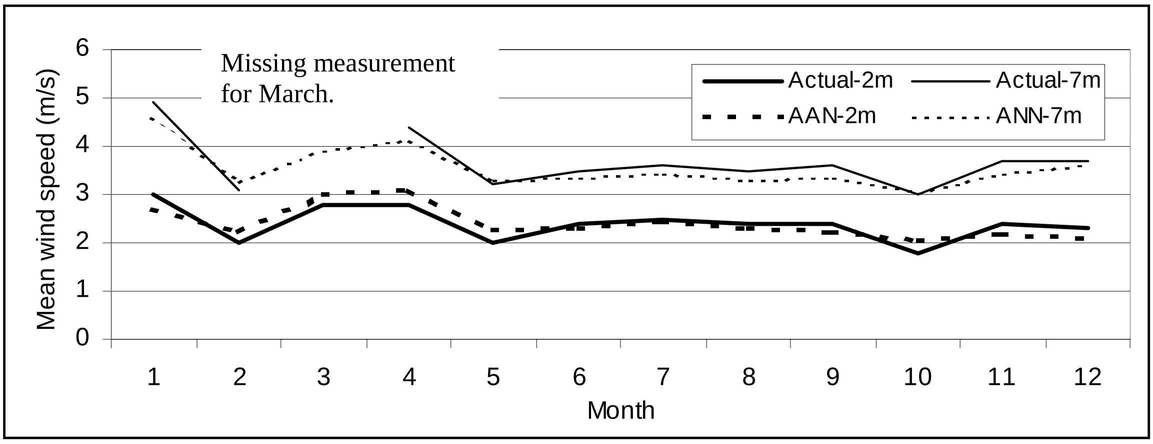

Figure 5. Mean wind speed for network using 5 input parameters.

Table 3. Maximum percentage differences of the annual results of the two networks.

Network architecture	Mean wind speed-Actual		Mean wind speed-ANN predicted		Percentage difference	
	Height-2m	Height-7m	Height-2m	Height-7m	Height-2m	Height-7m
11-input neurons	2.4	3.35	2.43	3.52	1.2	5
5-input neurons			2.4	3.41	0	1.8

CONCLUSIONS

The purpose of this work is to train an artificial neural network to predict the mean monthly wind speed in regions of Cyprus where data are not available. Data for the period 1986-1996 have been used to train the network whereas data for the year 1997 were used for validation. Both learning and prediction were performed with adequate accuracy. Two multilayered network architectures of the same type have been tried one with eleven neurons in the input layer and one with five. The second one proved to be more successful in the accurate prediction of the mean wind speed. The maximum percentage difference for the validation set was confined to less than 1.8% on an annual basis, which is very adequate. The network, with five inputs, can be used to fill-in missing data from a database whereas the second, with eleven inputs, can be used for predicting mean wind speed in other nearby locations. In the former the station can be located within the area marked by the three stations (interpolation) or outside (extrapolation).

As the present model proved successful in predicting the mean monthly wind speed, we are planning to extent this work for predicting average monthly wind speed for the whole island in order to establish areas of high wind potential.

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