Toplam Elektron Yoğunluğu Değerlerini Sinirsel Ağlar Kullanarak Öngörüde Bulunma

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Özet: *Veri sürüşlü yaklaşımların, fiziksel olguların öğrenilip modellenmesi için Yer'e yakın uzay konusunun doğrudan doğruya yararında kullanılabilirliği öne sürülmüştür. Bunun için tek temel gereksinim, olgular için simgeleyici verilerin bulunabilirliğidir. Sinirsel Ağ tabanlı yaklaşımların iyonosferik süreçleri modellemede ümit verici olduğu gösterilmiştir. Bu çalışmada, Sinirsel Ağlar kullanılarak Yer-uzay ve uydudan uyduya iletişimde karışıklıklara karşı 'TEC' değerlerinin 1 saat önceden öngörüde bulunulması yapılmıştır.*

Abstract: *It is proposed that the data driven approaches are applicable to learn and model the physical phenomena under the direct interest of the near Earth space task. The only basic requirement for this is the availability of representative data for the phenomena. It has been demonstrated that the Neural Network based approaches are promising in modeling of the ionospheric processes. In this work forecast of the TEC values 1 hour in advance to treat disturbances in Earth-space and satellite to satellite communications has been made by using Neural Networks.*

1. Introduction

Radio waves are propagated via ionosphere. Unpredictable variability of the ionospheric parameters due to disturbances limits the efficiency of communications, radar and navigation systems, which employ HF radio waves. The number of electrons in a column of one meter-squared cross-section along a path through the ionosphere is named as the total electron content (TEC). Forecasting of the TEC values is crucial for satellite based navigation systems especially in the stormy weather conditions.

Neural Network based approaches are promising in modeling of the ionospheric processes [2][3][4][5][6][7]. In this work forecast of an ionospheric process, the TEC variation, using Neural Networks has been made 1 hour in advance. Neural Network models are designed and trained with significant inputs. The basic inputs for the model are the temporal inputs, planetary magnetic activity indices, the present TEC value, first difference, second difference and relative difference of TEC values. The Neural Network architecture has one input layer with the inputs, one hidden layer with the neurons and one output layer with the output: 1 hour in advance forecast value of the TEC. Levenberg-Marquardt Backpropagation Algorithm is used in training the Neural Network based model. Then the trained Neural Network is used to forecast the TEC values 1 hour in advance.

2. Preparation of Data

The TEC data of the station Mortelliccio by the SIRIO - CNR ("Consiglio Nazionale delle Ricerche") [1] is used in this work. The time periods of the TEC data for development and operation modes are selected as follows:

Table 1. Selection of the time periods for the input data

<table>
<tr><th></th><th>Year</th><th>Month</th><th>Day</th></tr>
<tr><td>Train</td><td>1978</td><td rowspan="2">October
and
November</td><td rowspan="2">274 275 276 277 278 279 280 284 285 286 287 288
289 290 291 292 293 294 295 296 297 298 299 300
306 307 308 313 314 315 316 317 318 319 320 321
322 323 324 325 326 327 328</td></tr>
<tr><td>Test &Validation</td><td>1979</td></tr>
</table>

3. Construction of the Neural Network Based Model

The construction work of the Neural Network based model was carried out in the "development mode" and "operation mode." The development mode is composed of "training phase or learning phase" and "test phase." Data sets of same month, different year are used for training and validation phases as on Table 1. Training data and "Levenberg-Marquardt Backpropagation" algorithm are used for training. As the training advances, the training error starts to decrease, and it eventually goes to zero, which corresponds to the memorization. Memorization means the loss of the generalization capability of the Neural Network. To prevent memorization, the training is halted, and independent validation data are used. Errors are calculated and noted. Training is restarted, and the training cycle is repeated. The decrease in the validation error is noted. When the gradient of the error in the "validation phase" becomes near zero, a "stop training" signal is produced, and thus the training is terminated. The model is then ready for its actual use in the operation mode for forecasting of the TEC. In the operation mode the validation data are used for calculating the errors, point by point, to measure the performance of the model.

The value of the TEC at the time instant k is designated by $f(k)$. The 9 inputs used for the Neural Network are as follows:

1. The present value of the TEC: $f(k)$,
2. First Difference: $\Delta_1(k) = f(k) - f(k-1)$,
3. Second Difference: $\Delta_2(k)=\Delta_1(k) - \Delta_1(k-1)$,
4. Relative Difference: $R\Delta(k) = \Delta_1(k) / f(k)$,
5. Minute of the day: m,
6. Trigonometric component of the minute of the day: $Cm = -Cos(2.\pi.m / 1440)$,
7. Day of the month: d,
8. Month of the year: M,
9. Linearly interpolated interplanetary magnetic activity index: lin_Kp.

The output is $f(k+1)$. It is the value of the TEC to be observed 1 hour later than the present time. There are 9 inputs, 8 hidden neurons and 1 output in the feed-forward structure. The Levenberg-Marquardt Backpropagation algorithm is used in training.

4. Results

In the operation mode, forecast of the TEC values one hour in advance is performed for the validation data set, minute by minute. Then the root mean square, normalized and absolute error values are calculated. Also the cross correlation coefficients are calculated.

The analyses and results cover a time interval between October and November 1979.

Table 2. Error Table when the linearly interpolated Kp values are used as input in training of the Neural Network and operation

# Data Sets	61697
Root Mean Square Error (el/sqm * 10^{16})	3.27811
Normalized Error	0.09284
Absolute Error (el/sqm * 10^{16})	2.26483
Cross Correlation Coefficient	0.98971

Figure 1 exhibits the TEC values versus the order of data points. Superimposed in a solid line are the 1 hour advance forecast values of the TEC. Figure 2 is the scatter diagram of the forecast and observed TEC values.

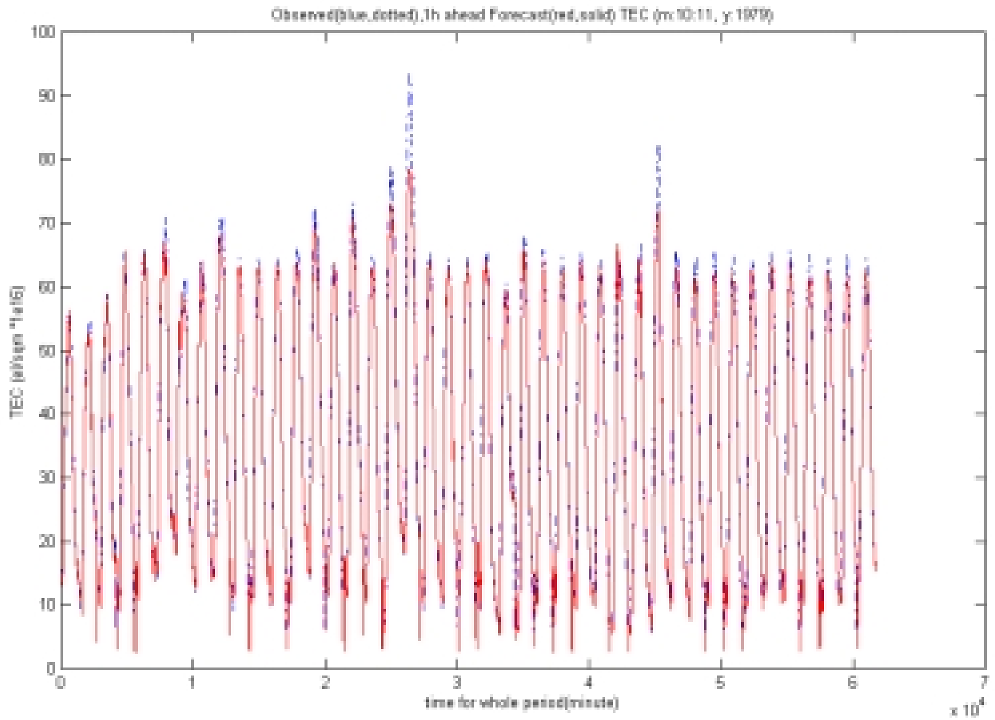

Figure 1. Observed (dotted), 1 hour ahead Forecast (solid) TEC values for the whole time of validation period: October-November 1979.

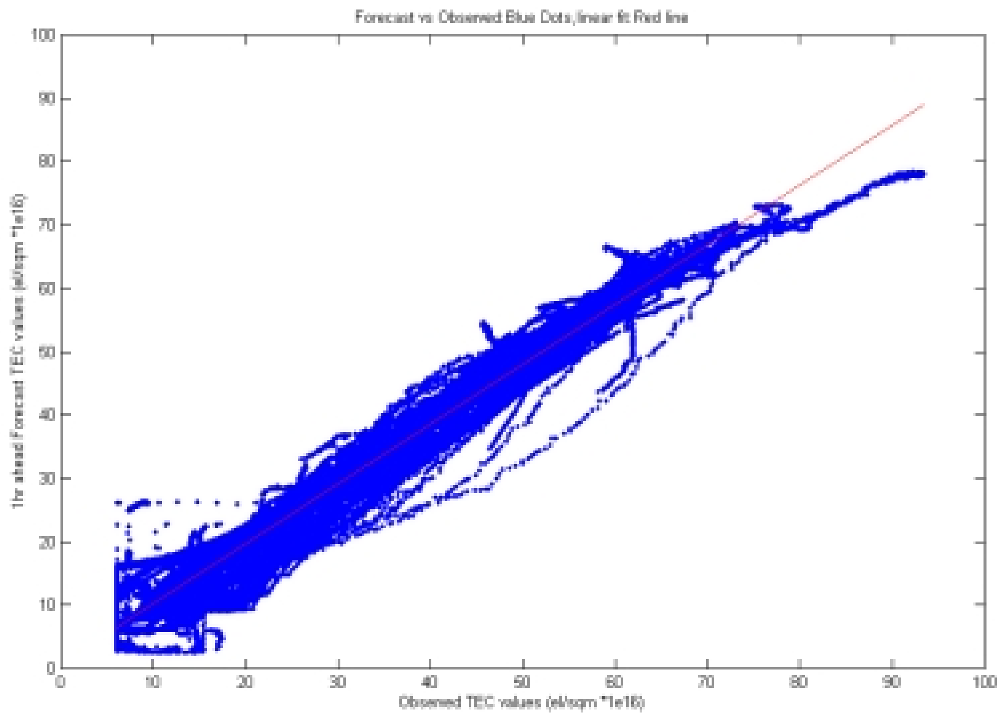

Figure 2. 1 hour ahead Forecast versus Observed TEC values (dots) with the linear fit line.

It is seen in the scatter diagram shown in Figure 2 that the deviations from straight line are small. Therefore the correlation coefficients are very close to unity. In other words, the Neural Network model learned the shape of the inherent nonlinearities. It is also observed that the fitted line has a slope close to 45° passing through the origin. Therefore the forecasting errors are small. This fact is the indication of the Neural Network system reaching the correct operating point. In other terminology, the Neural Network system reaches the global minimum.

5. Conclusions

Unpredictable variability of the ionospheric parameters due to disturbances limits the efficiency of communications, radar and navigation systems, which employ HF radio waves. Forecasting of the TEC values is crucial for satellite based navigation systems especially in the stormy weather conditions.

In this work forecast of an ionospheric process, the TEC variation, using Neural Network based model was made 1 hour in advance. The model learned the shape of the inherent nonlinearities and the system reached the correct operating point.

As a general conclusion, it is shown that properly constructed Neural Network based systems, trained and tested with properly organized data, are promising in modeling the complex nonlinear processes, such as the TEC variation.

Summarizing, the main contributions of this work are as follows :

1) organization of representable data for teaching complex processes,
2) Neural Network based modeling of a highly complex nonlinear process such as the TEC variation, and
3) general demonstration of learning capability by calculating cross correlations and general demonstration of reaching a proper operating point by calculating errors.

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