Title:

Forecasting Ionospheric Total Electron Content Using Signal Processing Techniques and LSTM

By

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ABSTRACT:

The forecasting of ionospheric Total Electron Content (TEC) is necessary for initiating measures to improve the performance of GNSS systems in modern technological infrastructures and applications. The TEC signal derived from GNSS signals is nonstationary and nonlinear due to temporal and spatial variations. Therefore, it is critically important to properly model and analyze the behavior of ionosphere. This study presents a hybrid deep learning, sample entropy and signal processing technique to present CEEMDAN-SE-LSTM model for predicting the nonstationary and nonlinear TEC signals. The proposed model is developed using the GNSS data obtained from the stations in China and Pakistan region and is evaluated in different conditions of ionosphere. The efficacy of the model has been established by comparing the forecasted TEC from the proposed model with the other machine learning and empirical models.

The first contribution of this research is development of hybrid model by combining the LSTM network and CEEMDAN signal processing technique to accurately predict the TEC signals. The CEEMDAN technique reduces the non-linearity of the TEC signal by decomposing it into several intrinsic mode functions (IMFs) which are then predicted by the LSTM network with better accuracy. However, the CEEMDAN-LSTM model is time and computationally intensive which limits their utilization especially for short duration forecasting.

As a second contribution of this research, the hybrid CEEMDAN LSTM model computational performance is further improved without reducing the accuracy of prediction. This is achieved by using the sample entropy by grouping the decomposed signal by IMFs and adding the grouped IMFs. These grouped IMFs are then processed through the LSTM network which drastically improved the computational cost without affecting its performance. The combined model is known as CEEMDAN-SE-LSTM model to predict the ionosphere signal.

As a third contribution to this research, the proposed CEEMDAN-SE-LSTM model was tested on the ionosphere of two regions namely China and Pakistan. For the China region GNSS data was obtained from the IGS LHAZ, POL2 & STK2 stations to forecast TEC. Similarly, for the Pakistan region GNSS data was obtained from the Sukkur, IGS IISC & YIBL station. The prediction results of the proposed model were compared with Neural Network, LSTM, and the International Reference Ionosphere (IRI) model. The RMSE and MAE of the predictions from the proposed model were observed to be 50% and 70% better compared to LSTM and the Neural Network models.