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Application of Curve Fitting and Surface Fitting Tools for High Leverage Points and Outliers of Wind Speed Prediction

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Abstract: ***Climate change is generally accepted as the greatest environmental challenge our world is facing today. Together with the need to ensure long-term security of energy supply, it imposes an obligation on all of us to consider ways of reducing our carbon footprint and sourcing more of our energy from renewable sources. Wind energy is one such source and this paper proposes a few methodologies to predict the speed of wind. Multivariate regression model, curve fitting, surface fitting model and time series model are implemented for the test data collected from a wind farm. The results obtained are then compared with the actual values available for validation.***

Keywords: multivariate regression; time series; wind speed; prediction; curve fitting; surface fitting.

1. Introduction

Intermittency of wind is the biggest challenge in implementing wind-energy as a reliable autonomous source of electric power. Energy crisis, global warming, depletion of fossil fuels are the major factors looming the world today. Adequate utilization of renewable energy sources like wind, solar, biomass etc. proves to be the only alternative to overcome these problems. Because of the indeterminate nature and complementary behavior of wind and solar energy, many researchers are putting their effort towards hybrid energy systems. A hybrid energy system uses a combination of sources like wind and solar along with a battery and Diesel Generator set.

Optimal allocation of the available resources is one of the challenges faced in the design of hybrid energy systems. For a well-planned system, it is essential to have accurate predictive models of the wind and solar sources. Wind energy is directly dependent on the wind speed available at that location and this speed is extremely erratic. Hence, a model is needed for accurate prediction of wind speed. This paper proposes a few predictive models for wind energy using regression and curve fitting.

A wide variety of methods were proposed in the literature for wind forecast [1]. Persistence method or the 'Naïve predictor is the simplest and fundamental prediction model. Physical approach makes use of Numerical Weather Predictor model such as global forecasting system; prediktor etc. Statistical approaches include time series forecasting methods and Artificial Neural Network models. A few hybrid models are also proposed which used a combination of the above mentioned methods. This paper proposes four different models for wind forecast based on regression, curve fitting and surface fitting.

The correlation between the physical parameters was obtained by using the statistical data analysis tools. Linear regression, nonlinear regression, curve fitting and surface fitting models were developed. A time series model was also implemented for the purpose of tracking the peak overshoots and undershoots. Here, time was defined as a variable along with temperature, pressure and relative humidity and the previous value of the wind speed was used as the input. Errors for the various models were also calculated.

2. Parameters Used

There are various variables on which wind speed depends upon and this paper presents the statistical relationship among these variables which impact the wind speed in a wind farm in Bagalkote region in Karnataka using MATLAB. The parameters are typical of any moderate tropical country. The variables used are temperature, relative humidity and atmospheric pressure.

2.1. Atmospheric Pressure (P)

It is the force per unit area exerted on a surface by the weight of air above that surface in the atmosphere of Earth. In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point. On a given plane, low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. Likewise, as elevation increases, there is less overlying atmospheric mass, so that atmospheric pressure decreases with increasing altitude. The unit of atmospheric pressure used in this paper is consistent throughout and it is mm of Hg.

2.2. Relative Humidity (RH)

It is the ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a prescribed temperature. The relative humidity of air depends on temperature and the pressure of the system of interest. There is a considerable degree of difference between the relative humidity measured indoors and that measured outdoors in regions such as wind farms and those at altitudes of the shaft locations. Relative humidity, being a ratio has no unit for and the numbers used in this paper are expressed as a percentage.

2.3. Temperature (T)

A temperature is a numerical measure of hot and cold. Its measurement is by detection of heat radiation or particle velocity or kinetic energy, or by the bulk behaviour of a thermometric material. The kinetic theory indicates the absolute temperature as proportional to the average kinetic energy of the random microscopic motions of their constituent microscopic particles such as electrons, atoms, and molecules. The basic unit of temperature in the International System of Units (SI) is the Kelvin. For everyday applications, it is often convenient to use the Celsius scale, in which 0°C corresponds very closely to the freezing point of water and 100°C is its boiling point at sea level.

2.4. Wind Speed or Wind Velocity (Ws)

Wind is caused by air moving from an area of high pressure to low pressure. Wind speed affects weather forecasting, aircraft and maritime operations, construction projects, growth and metabolism rate of many plant species, and countless other implications. It is now commonly measured with an anemometer but can also be classified using the older Beaufort scale which is based on people's observation of specifically defined wind effects. The unit of wind speed used in this paper is consistently meters per second.

3. Data Acquisition

The data used for the proposed work was collected from a wind farm in Bagalkot, Karnataka. The recorded data consists of values of Air Temperature, Relative Humidity, pressure, wind speed and the wind direction measured for different altitudes, for every minute over a period of six months. For analysis, one particular altitude values were considered. The choice is made based on the fact that wind velocity is higher in upper strata of atmosphere thereby having more potential to generate wind energy[6]. The data in Microsoft Excel format is imported to MATLAB for the analysis or modelling.

4. Modelling for Wind Speed Prediction

In regression models, the forecast is expressed as a function of certain parameters which influence the outcome. Regression gives an explanatory model that relates output to various inputs which facilitates a better understanding of the situation and different combinations of inputs can be tested and their effects on the forecast can be studied. The forecasting parameter is the wind speed and the independent parameters used are atmospheric pressure, relative humidity and average temperature.

Linear and non-linear regression models are developed. Linear regression model is implemented by restricting the number of dependent variables to one, which is wind speed. Multivariate linear regression is often found to be more efficient and useful since it considers the effects of all the parameters that may have a significant effect on the dependent variable present. In non-linear regression, the inputs or the independent variables can have a non-linear relation with the wind speed.

Curve fitting tool in MATLAB is used to find the best fit between wind speed and one of the input variables. The best fit is chosen to develop the model. Surface fitting is another technique used to find the best fit between wind speed and two of the input variables. A similar model was developed. A time series model is also developed which takes the previous value of wind speed and time as the inputs.

4.1. Linear Regression model

The input parameters considered for the linear regression are combinations of the measured quantities (Pressure, Temperature and Relative Humidity). A number of models have been tested and the best model has been chosen which is shown in equation 1. The inputs of temperature, pressure, relative humidity, product of temperature and relative humidity, product of temperature and pressure were observed to yield the best results. The plot is shown in Figure 1

$$WS= -30.079*T+ 0.1257*RH- 0.0353P- 0.006*T*RH + .044*T*P \quad (1)$$

4.2. Non-linear Regression model

A non-linear relation between the various combinations of inputs was modelled using regression tool. It was found from the analysis of theoretical data that there is proportionality between wind speed and square root of pressure. This relationship was also considered in the model. Various combinations were tried out and the best of the lot was chosen. The model is shown in equation 2. The results are shown in fig.2.

$$WS= 0.3143*T+ 0.0408*RH - 0.2633*\mathrm{sqrt}(P) \quad (2)$$

4.3. Curve Fitting model

To implement this model, first the relationship between wind speed and pressure is derived. This is obtained by plotting the scatter diagram between pressure and wind speed. The best fit is plotted as shown in fig.3. There is additional option for including weights in the data points. The model thus obtained is shown in equation 3.

$$WS = -9.565e\text{-}010 *(P)\text{^}3.757+53.08 \quad (3)$$

4.4. Surface Fitting Model

The inputs yielding best results were those of pressure and relative humidity and the surface fit is as shown in Figure 5. The output graph obtained was slightly different from that obtained from the previous functions and is given by Figure 6. The difference noted was the increased correlation between the inputs and lower values of wind speed. The obtained model is given in equation 4.

$$WS= -1525 +13.35*RH+4.131*P+ 0.00332*(RH)^2 - 0.01909*RH*P -0.00278*(P) \quad (4)$$

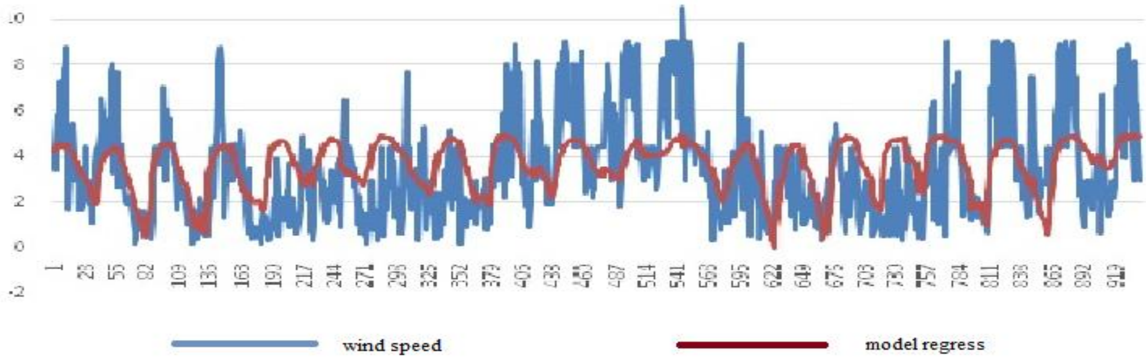

Figure 1: Plot for linear regression model

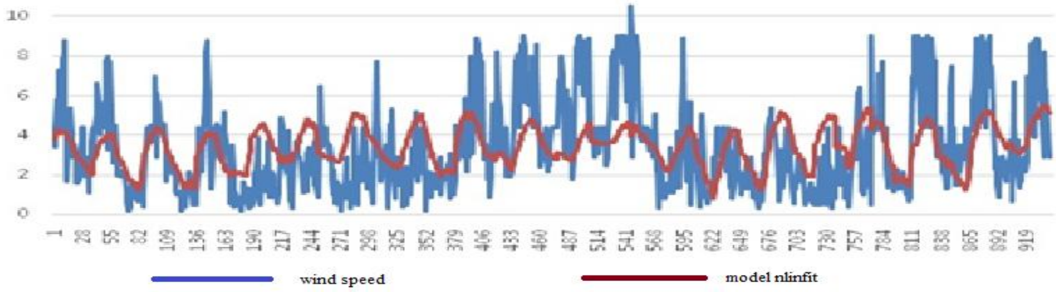

Figure 2: Plot for non-linear regression model

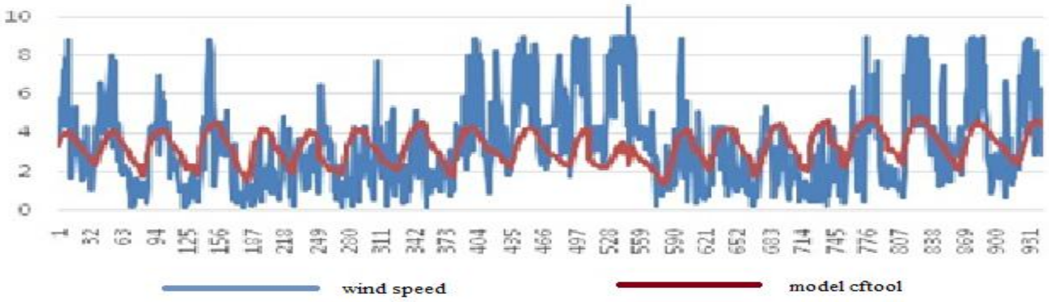

Figure 4: Plot for curve fitting model

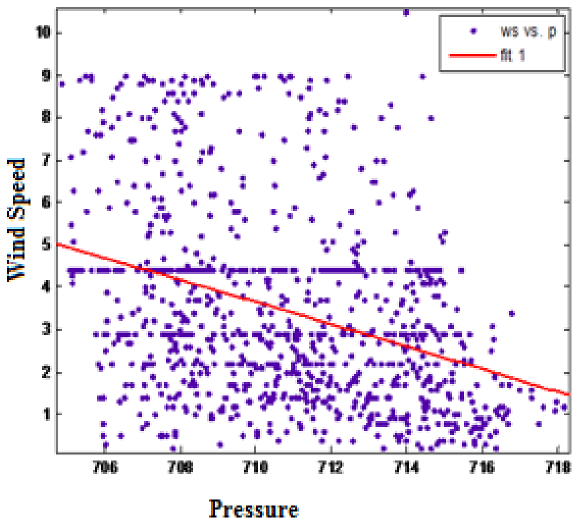

Figure 3: Scatter diagram for curve fitting

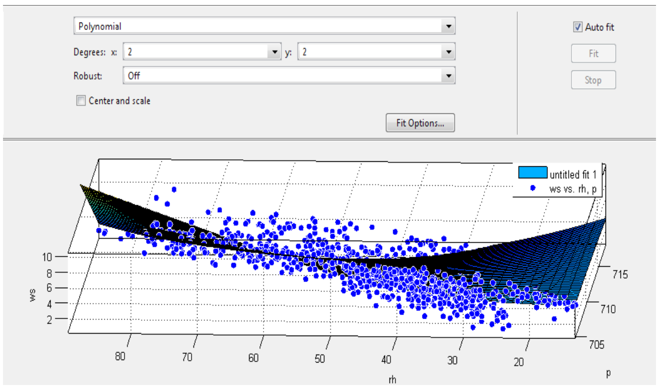

Figure 5: Scatter diagram for surface fittng

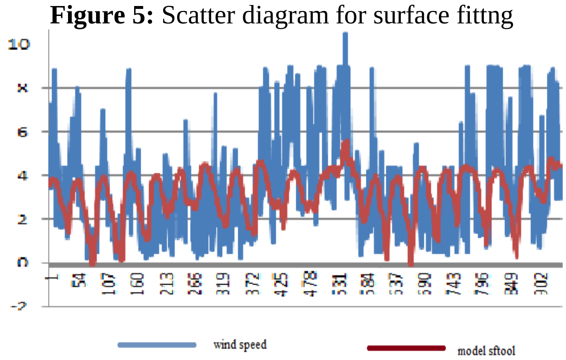

Figure 6: Plot for surface fitting model

4.5. Time Series Model

Even in the best fit, the generated curve matched the original curve in phase alone but not in magnitude. Observing all the results, it can be concluded that an open loop system will never give the required correlation. Hence, feedback systems were incorporated in order to account for the mismatched magnitudes. Thus, time series models were implemented to improve the response.

In time series modelling, time was defined as a new variable along with temperature, pressure and relative humidity. The present value was predicted with the help of previous value and the error. The input vector 'X' was defined for an intercept along with temperature and pressure.

The output curve showed better correlation with the input. But, the output had very large offshoots causing large errors. The output was enhanced by providing error correction by shifting the output waveform by trial and error. Figure 7 shows plot. The following is the equation obtained after modelling using time series is given in eq: 5

$$WS(time+1) = WS(time) + 0.2018 * T - 2.0873 \quad (5)$$

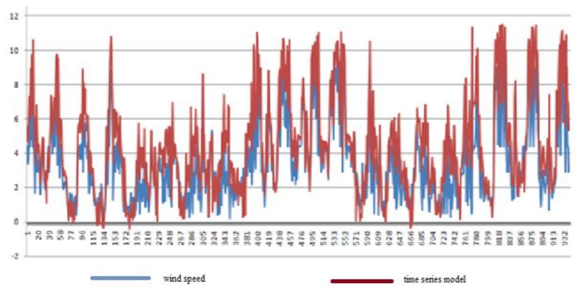

Figure 7: Plot for time series model

5. Results and Discussions

As seen, the predicted values form a graph that is following the trend of the plot formed by the actual values. The ups and downs are followed, but the numerical data differs in the case of multivariate regression models. In the case of time series model both trend and the magnitude matched to a greater extent.

Table 1: Comparison of Errors

Model	*SSE*
Model regress	3763.851
Model nlinfit	3796.608
Model cftool	4178.766
Model sftool	3746.625
Time series model	3568.12

Table 1 shows the values of sum of squared errors for the various models implemented.

6. Conclusion

Five different models were implemented for the prediction of wind speed. It can be observed from the results and calculated errors that the time series model has the least sum of squared errors taken for about 942 points. Hence the model with feedback elements yielded the best result. The time series element solved the magnitude mismatch problem and predicted wind speed with the highest accuracy as can be seen in the output.

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