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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (23): 7884-7888, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.7884.7888

Design and Implementation of C#-based Processing System for the Wind Data Observed in Mountainous Bridges

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Abstract: In this study, we developed a data processing program for the wind on bridge based on C# programming language, Windows Presentation Foundation (WPF) framework and the idea and process used in analyzing and processing wind data. The program proposed functioned in data segmentation, processing of bad points and calculating of wind speed, wind direction, turbulence intensity, gust factor, integral scale and power spectral density. Moreover, it realized the rapid and automatic calculation of the wind characteristic parameters and convenient processing of the massive wind data observed.

Key words: Mountainous area, bridges, wind observation, C#, system development

INTRODUCTION

Wind observation technology is one of the most direct and authentic means to get long-term complete wind speed databases in researching the wind characteristics of mountainous areas(Surry, 1991; Zhang et al., 2008). However, wind observation starts relatively late in China. Especially in complex mountainous terrains, wind observation faces great difficulty in grasping and controlling the meteorological and terrain conditions. Moreover, the wind characteristic parameters under complex mountainous terrains have not been clearly specified in China. Therefore, it is of great significance in developing the wind characteristic observation in mountainous areas (Zhang *et al*., 2010). At present, the ultrasonic anemometers used in wind environment-monitoring generally make a record by 0.15 s. In one testing site, the wind speed data recorded are up to tens of millions of lines in one month. Therefore, the wind parameter statistics and analysis using such massive and complex original data should rely on some mathematical softwares. Unfortunately, general mathematical softwares, such as matlab, fail to meet the requirements in calculating speed and processing ability. Therefore, it is necessary to develop a specific processing program for wind characteristic analysis to realize the intelligent and fast analysis and calculation on the wind data observed. The results obtained lay basis for the bridge wind tunnel test and wind resistant design.

WIND DATA PROCESSING METHOD

Wind observation data were mainly treated to obtain the following wind characteristic parameters: mean wind speed, wind direction, wind attack angle, wind profile index, turbulence intensity, gust factor, turbulence integral scale and power spectral density function. In these parameters, wind profile fitting index, turbulence integral scale and power spectral density function are obtained by further calculation basing on the pretreatment and basic treatment on the wind data observed.

Maximum 10-min wind speed: In this section, wind characteristics are classified into mean wind characteristics and fluctuating wind characteristics to study the influences of wind on bridge structure. Mean wind characteristics are consisted of the basic field wind speed, the attitudinal distribution law of wind speed and the attack angle and direction of mean wind speed etc.. The mean wind therein is defined basing on a certain time length due to the great uncertainty of wind variations in short time period. Therefore, it is deem to give a time interval for mean wind speed. According to the bridge wind-resistance design code in China, the time interval is set as 10 min (Professional Standard PRC, 2004). In assumption of that the instantaneous wind speed per sec are $X_1, X_2, ..., X_n$ n = 6000, respectively, maximum 10-min mean wind speed can be obtained using moving average:

$$U_1 = \frac{x_1 + x_2 + ... + x_n}{n} \tag{1}$$

$$U_2 = \frac{x_2 + x_3 + ... + x_{n+1}}{n} \tag{2}$$

The 10-min mean wind speed is:

$$U_i = \frac{1}{n}\sum_{j=i}^{i+n} x_j x_j = \sqrt{U^2{}_{xj} + U^2{}_{yj}} \tag{3}$$

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The daily maximum 10-min mean wind speed is calculated by:

$$U^D_{max} = Max(U_i) \quad (4)$$

The monthly maximum 10-min mean wind speed is:

$$U^M_{max} = Max(U^D_{max}) \quad (5)$$

where, U_{xj} and U_{yj} refer to the wind speeds on x and y coordinates recorded by anemometer at time point of j, respectively; X_j represents the horizontal wind speed at time point of j; U_i is10-min mean wind speed.

Wind direction: The mean of instantaneous wind direction was directly calculated by the wind direction recorded in the ten minutes of maximum wind speed. Then the direction β^D_{max} of daily maximum 10-min mean wind speed was getable. Therefore, the direction of the monthly maximum 10-min mean wind speed was:

$$\beta^M_{max} = Max(\beta^D_{max}) \quad (6)$$

Turbulence intensity and gust factor: Turbulence characteristics were analyzed based on 10-min time interval (Simiu and Scanlan, 1996). In the analysis, samples were firstly divided into 10-min subsamplesby date and time sequences to recalculate the efficiency of subsamples. Only the subsample with efficiency of 95% above could be used in the analysis of turbulence characteristics. Moreover, in analyzing the integral scale and spectrum frequency, the invalid data points deleted should be supplemented on corresponding time positions by interpolation to ensure information integrity and sample length consistence. Using Eq. 7, the turbulence intensity of daily maximum 10-min mean wind speed could be Fig. out:

$$\varepsilon = \frac{U_r}{U^D_{max}} \times 100\% \quad (7)$$

where, U_r refers to the Root Mean Square (RMS) of the maximum 10-min mean wind speed.

The fluctuation intensity can also be represented by gust factor (Sharma and Richards, 1999). Gust factor $G(t_g)$ is defined as the ratio of the maximum mean wind speed in gust duration $t_g$with mean wind speed in basic time interval. In structural wind project, gust duration is generally set in 2-3 s. In this study; it is 3 s:

$$G_u(t_g) = 1 + \frac{max[\overline{u}(t_g)]}{U(z)} \quad (8)$$

$$G_v(t_g) = \frac{max[\overline{v}(t_g)]}{U(z)} \quad (9)$$

where,u(t_g) and V(t_g) are the mean speeds of along-and across-fluctuating wind in t_g. It is visible of that gust factor is associated with gust duration t_g. Generally, the bigger the t_g, the smaller the corresponding gust factor (Miyata *et al*., 2002). Turbulence intensity and gust factor are two dimensionless and highly discrete parameters related to mean wind speed, time interval, surface roughness and the height of test point.

THE RUNNING ENVIRONMENT OF SYSTEM

Function design of the system: Using the analysis method on the wind data observed, the system realizes the automatic and rapid calculation of wind characteristic parameters. The functions of the system are indicated as follows:

- Pretreatent on wind speed data The monthly data files were divided into daily data files (a day refers to 0:00:00-23:59:59) and unrelated parameters were deleted. Moreover, the recording format of the time of the files was rewritten in h-min-sec and automatically saved as.dat files in form of date-month. For the time frame with more bad points, the bad points with continuous records of more than 10 min were directly deleted and corresponding time frames were recorded. While for those less than 10 min, parameters were obtained by interpolation using the data in adjacent 10 min
- Calculations of daily maximum 10-min mean wind speed, extreme wind speed and corresponding wind directions Daily wind speed data files were firstly read in and segmented into subsamples by 10-min time interval. Subsequently, the variations of mean moving wind speed and corresponding directions were investigated to acquire the daily maximum mean wind speed, extreme wind speed and corresponding wind directions
- Calculations of turbulence intensity, gust factor, integral scale and power spectrum intensity Calculations of turbulence intensity and gust factor etc. were performed by sampling on daily maximum 10-min mean wind speed. The results obtained were preserved in a specified path in formats of.dat

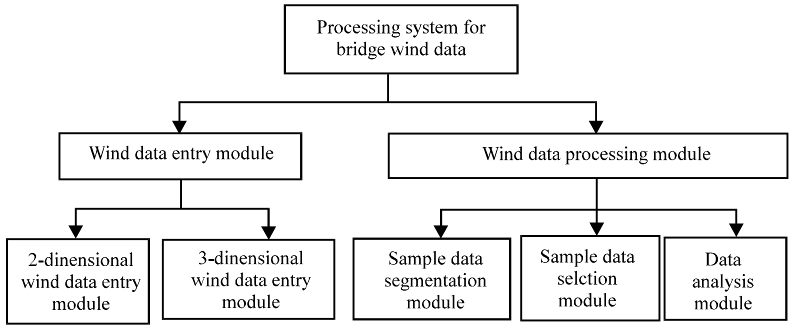

Fig. 1: Structure of bridge wind data processing system

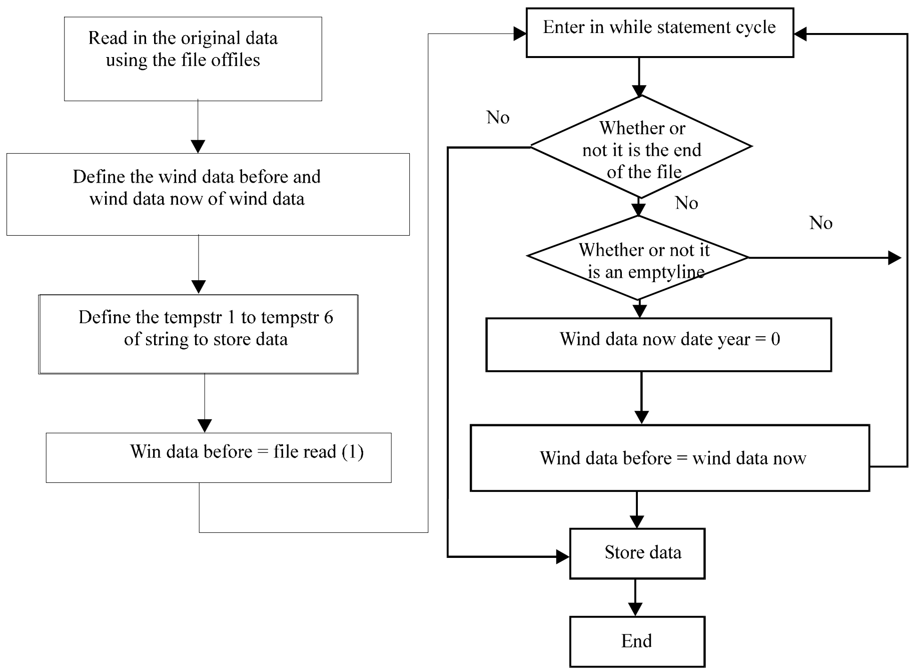

Fig. 2: Detail process of the pretreatment

The system consists of a main interface and two submodules. Results could be automatically yield simply by filling parameter values according to data entry standards and then reserved in a designated file of user. Meanwhile, input and output information were saved in the data file to facilitate filing, viewing and systemizing. Fig. 1 shows the structure of the system:

Data pretreatment: Pretreatment mainly aims at segmenting the wind observed data of each month into daily files by days. To realize this function, a windData is designed in the program to instantiate the two objects (wind Data Before and wind Data Now) during the processing, respectively. The wind Data Before therein is used to store the prior wind speed data read in, while wind Data Now is employed to reserve the following wind speed data. If wind Data Before. day is equal to wind Data Now. day numerically, the data of the same day are stored into the same file in forms of Data Pro2D (two dimensional data) or Data Pro3D (three dimensional data) to realize data segmentation. Fig. 2 shows the whole detail process of the pretreatment.

Data calculation: This module is mainly designed for the processing of observed wind speed data, namely, the interpolation calculation on invalid data using interpolation function Inter Polating Function (). MaxWind object was valued by the data in the maximum line of extreme wind speed, while max Wind Speed is valued by the maximum vector of the 10-min mean moving

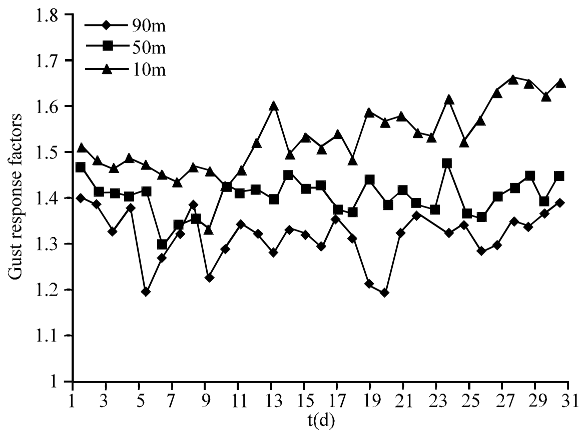

Fig. 3: Time-history curve of the gust factor: along-wind direction

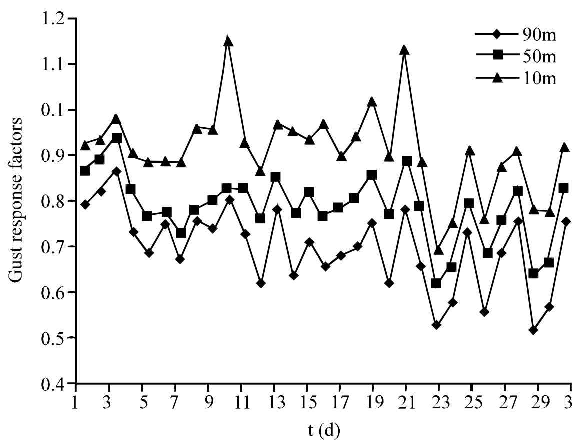

Fig. 4: Time-history curve of the gust factor: cross-wind direction

wind speed. Similarly with max Wind Speed method, the parameters such as turbulence and gust factor etc. can be obtained using corresponding 10-min data.

Due to the hugeness and uncertainty of wind characteristic data, traditional arrays are replaced by the ArrayList dynamic array of C# in the program proposed. As is a complex version of Array, ArrayList realizes dynamic state increase, element decrease, flexible setting of array size etc.

Gust factor: According to the measured data, the ratio of the maximum mean wind speed and horizontal mean wind speed in the gust duration time t_g measured by sensors at different heights was calculated (Shum *et al*., 2008). Using this ratio, the gust factors in cross-and along-wind directions were obtained. Then the gust factors were weighted and averaged to acquire the gust factor value for each day. Finally, the variation laws of the gust factors at different heights were derived, that is, the gust factor's time-history curves were obtained (Xie *et al*., 2009). For brevity's sake, only the January time-history curves for the gust factor at heights: 10 m, 50 m and 90 m above the arch springing are shown as Fig. 3 and 4.

For mountainous terrain, in the along-wind direction, the maximum value of the gust factor at 10 m above the arch springing was observed in August, with a value about 1.6, while that at 90 m occurred in January, with a value of about 1.4; in the cross-wind direction, the maximum value of the gust factor at 10 m above the arch springing was observed in January, with a value about 1.15, while that at 90 m above the arch springing occurred in January and March, with a value of around 0.8. On the whole, the down-wind turbulence intensity in mountainous terrain was higher than that on the plains. Turbulent winds can easily cause buffeting of bridge structures.

CONCLUSION

In bridge wind resistance design, the wind speed of bridge is designed basing on basic wind speed. The bridges in the mountainous areas show complex terrains and thus face very complex wind fields in theirs sites. However, researches concerning the wind characteristics in the mountainous areas have attracted little attention of the bridge wind project field around the world. In China, the current wind resistant design codes also fail to list clear treatment methods. Wind environment field observation is a common and useful technique. According to the idea and process in analyzing and processing bridge wind data, this study developed a processing program for bridge wind data. This program functioned in data segmentation, processing of bad points and calculations of wind speed, wind direction, turbulence intensity, gust factor, integral scale and power spectral density. Moreover, it realized the automatic and fast calculation of wind characteristic parameters using the massive wind data observed. This program was applicable in Windows XP/Windows Vista/Windows 7 environments by debugging and convenient in processing the wind data observed.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the support of this research by National Natural Science Foundation of China No. 50778185

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