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A wireless high-frequency anemometer instrumentation system for field measurements

Guoqing Huang*, Liuliu Peng[a], Yanwen Su[b], Haili Liao[c] and Mingshui Li[d]

Research Center for Wind Engineering, School of Civil Engineering,
Southwest Jiaotong University, Chengdu, Sichuan 610031, China

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Abstract. Field measurement of wind characteristics is of great significance for the wind engineering community. High-frequency anemometers such as ultrasonic anemometers are widely used to obtain the high-frequency fluctuating wind speed time history. However, conventional instrumentation systems may suffer from low efficiency, non-real time transmission and higher maintenance cost, and thus are not very appropriate in the field measurement of strong winds in remote areas such as mountain valleys. In order to improve the field measurement performance in those remote areas, a wireless high-frequency anemometer instrumentation system for field measurement has been developed. In this paper, the architecture of the proposed instrumentation system, and measured data transmission and treatment will be presented firstly. Then a comparison among existing instrumentation systems and the proposed one is made. It shows that the newly-developed system has considerable advantages. Furthermore, the application of this system to the bridge site located in the mountain valley is discussed. Finally, typical samples of measured data from this area are presented. It can be expected that the proposed system has a great application potential in the wind field measurement for remote areas such as the mountainous or island or coastal area, and hazardous structures such as ultra-voltage transmission tower, due to its real-time transmission, low cost and no manual collection of data and convenience.

Keywords: field measurement; high-frequency anemometers; data wireless transmission; General Packet Radio Service (GPRS) network; cloud server; mountain area

1. Introduction

Knowledge of wind characteristics, such as the mean speed, fluctuation and direction, is of great significance for wind engineering. Their accuracy affects wind-induced structural response analysis and subsequent wind-resistance design of structures. Compared with wind tunnel testing and numerical simulation, field measurement provides more direct and accurate information for wind characteristics in nature. Also it serves as a benchmark for evaluating other experimental and

*Corresponding author, Professor, E-mail: ghuang1001@gmail.com
[a] Ph.D. Student, E-mail: pll234@163.com
[b] Ph.D. Student, E-mail: bridgeywsu@gmail.com
[c] Professor, E-mail: hlliao@home.swjtu.edu.cn
[d] Professor, E-mail: rcwe@163.com

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theoretical methods.

The severe winds such as hurricanes (or typhoons), thunderstorm downbursts and other gales have attracted a great deal of attention from meteorological and wind engineering communities due to their high destructiveness. To capture these transient winds in the field measurements, advanced instrumentation systems have been developed and applied. Mobile instrumented towers (e.g., Gast 2003, Schroeder and Smith 2003, Balderrama *et al*. 2011) have been deployed in the short-duration field measurement of hurricanes and thunderstorm downbursts. On the other hand, the long-term field measurement of wind data relies on temporarily established masts or towers (e.g., Cao *et al*. 2009, Hui *et al*. 2009a) or permanent structural health monitoring systems (e.g., Xu *et al*. 2000, Wang *et al.* 2013). It is noted that the data collection in the aforementioned schemes are based on wired transmission.

With the fast development of infrastructure in mountain areas, especially in China, the study of wind characteristics in these areas is becoming important (Xiang and Ge 2007). These winds are very intricate due to the influence of the complex terrain. With the development of techniques, the advanced instruments such as radar wind profiler and Doppler sodar are used to capture the mean wind speed in mountain-valley areas (e.g., Heo *et al*. 2003, Cohn *et al*. 2011). However, for the measurement of turbulent fluctuations in these areas, high-frequency anemometers such as ultrasonic anemometers are still the first choice (e.g., Turnipseed *et al.* 2003). In these remote areas, the internet and reliable power supply may not be available. Also the data collection is difficult. To overcome these difficulties, a data logger or radio transmitter/receiver is used to collect measured wind data (e.g., Turnipseed *et al*. 2003, Subramanian *et al*. 2005, Zhang *et al.* 2008). However, the former does not provide real-time data and also data saved on automatic memory cards need to be obtained manually and regularly. The latter requires a base station to receive measured data and the transmission distance is also limited (up to 10 km). Furthermore, the latter will be significantly affected by the power supply on the construction site.

Recently, GPRS or UMTS/HSPA/HSUPA network has been employed to collect data wirelessly. For example, the NRG anemometer system produced by American company WIND&SUN is widely used to collect wind data wirelessly in wind field measurements (Song *et al*. 2012). However, this instrumentation system is only available to transmit low-frequency wind measurement data, such as 10-minute mean wind speed. Also, researchers have developed an advanced wireless instrumentation system for wind speed and pressure measurement during hurricane events (Otero *et al*. 2009, Subramanian *et al*. 2011). This system works well for short-term field measurements using the multiple sensors. However, it may not be appropriate for long-term wind field measurements in remote areas, where limited anemometers will be involved.

In this paper, the development of a wireless high-frequency instrumentation system for wind measurement in the field is presented. The architecture of this newly-developed system, and the transmission and treatment of measured data will be described firstly. Then this system is compared with existing instrumentation systems. Subsequently, its application to the bridge site located in the mountain valley is discussed in detail. Finally, selected samples of measured data from the field are presented, and basic wind characteristics in this mountain valley area are also addressed.

2. Architecture of instrumentation system

The wireless transmission-based instrumentation system is mainly comprised of 4 units, which are shown in Fig. 1.

1) Data acquisition unit.

Generally, high-frequency anemometers such as ultrasonic anemometers acquire the wind speed data with sampling frequencies ranging from 4 Hz to 10 Hz (e.g., Chen *et al*. 2007, Song *et al*. 2012). It is noted that although this system was originally developed for the high-frequency anemometer, other data acquirement instruments with high sampling frequency such as thermometer, barometer and pressure sensor will be also suitable for this system.

2) Data transmission unit.

The high-frequency anemometer is connected to Remote Terminal Unit (RTU) module through a RS485 interface. The measured data from the anemometer are wired to the RTU module. This module has two components: Data Transfer Unit (DTU) and timer. The former is to collect data and transmit data wirelessly. In the situation of a bad GPRS network, the DTU allows for storing data, i.e., the DTU can buffer data temporarily. The function of the timer is to restart DTU automatically at small wind speeds (e.g., morning breeze) and at regular intervals (e.g., one month). In this way, the collapse of DTU can be avoided in the long-term operation.

3) Data treatment unit.

Via the GPRS network, the measured data are transmitted to a cloud server system from RTU modules according to the specified Transmission Control Protocol/Internet Protocol (TCP/IP). GPRS has features of wide cover scope, high-speed and real-time transmission, billing by data flow and so on. These features can sufficiently satisfy the demand for transmitting measured data from the high-frequency anemometer through GPRS network. The data treatment (receiving/processing) software is developed to reconstruct the original data from non-cached (instantaneously transmitted) and cached (transmitted later) data. With this software, the use of the computer or laptop can be avoided. Hence, the cost will be reduced, and the power supply and maintenance can be minimized. The detailed description is addressed in section 3.

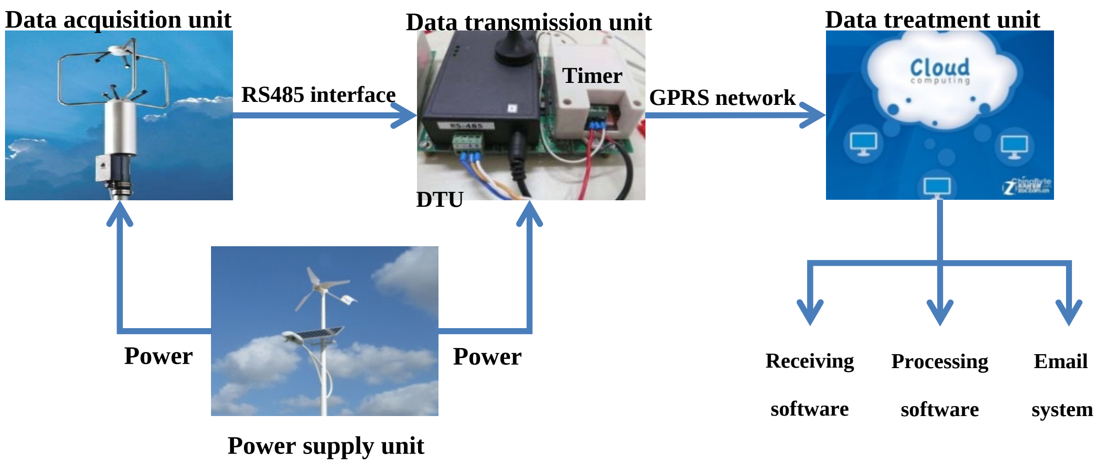


Fig. 1 Architecture of instrumentation system

4) Power supply unit.

A solar power supply unit is employed to provide power to data acquisition and transmission units. Because the solar power supply unit is susceptible to the weather, two approaches can be used to improve the performance of the power supply system. One is to increase the capacity of power supply by, for example, enhancing the capacity of the solar panel and lead-acid battery or using a wind and photovoltaic hybrid power system. Another approach is to save energy. Currently, the intelligent switch has been developed by authors, which can shut down the whole system when the 1-minute mean wind speed is lower than the threshold value (e.g., 6 m/s) and restart the system when the wind speed is larger than the threshold value. This approach is practical because 80-90% mean wind speeds are low (less than 6 m/s) based on the wind speed statistics from field measurements.

3. Data transmission and treatment

As mentioned above, the anemometer is connected to a RTU module. Consequently, the data acquired from the anemometer will be wired to RTU module simultaneously. If the network is good all the time, RTU module will transmit data in real time, and the software in a cloud server can receive and process the data synchronously. However, due to the possible interruption of data transmission (usually tens of seconds per time and 3-4 times per day) associated with bad GPRS network, the data in RTU module will be transmitted discontinuously. Hence, it is appropriate to consider the data to be transmitted in segments. Note that two states of the RTU module including online and offline in the following discussion are regarded as associated with a good and bad network, respectively.

Suppose that numbers 1 to 5 denote chronological segments acquired from the anemometer, as illustrated in Fig. 2. The first-in first-out (FIFO) principle is employed to transmit these measured data. If RTU module is online, the data receiving software automatically accepts data such as segment 1 and writes them into the text file. Once RTU module is offline, the receiving software will assign NAs (NA denotes not available) to the text file until the RTU module is online, which can be seen in segment 2. When the RTU module is online again, the cached data (segment 2) and subsequently measured data (segment 3) will be received by cloud server in order and appended into the text file after those NAs. If the offline time T2 is less than the maximum buffered time (MBT) of the RTU module, no data will be lost. Note that MBT is defined as the quotient of the cache memory divided by the data flow rate from anemometers.

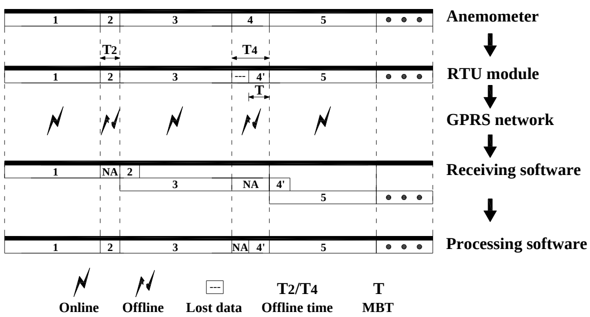


Fig. 2 Schematic diagram of data transmission and treatment

On the other hand, if the offline time is greater than MBT of RTU module, a part of data will be absent. For example, if the offline time T4 is greater than MBT, the beginning part of the data vanishes and the remainder (segment 4') can be transmitted to server. Again, the receiving software will assign NAs (length of T4) to the text file until the RTU module is online. As the RTU module resumes online, the cached data (segment 4') and subsequently measured data (segment 5) will be recorded in the text file after those NAs. For better monitoring data, a graphic user interface (GUI) is developed to illustrate the received data in real time (see Fig. 7).

Then processing software will scan the text file generated by the receiving software every one hour. If NAs are detected, the time duration of NAs will be determined firstly. When it is smaller than or equal to MBT, those NAs will be deleted directly and ensuing data will be connected to the data segment before NAs (see segments 1 and 2). It will be a little difficult to process data when the time duration of NAs is greater than MBT. For example, if T4 is greater than MBT, NAs in the beginning part of segment 4 (Its duration is T4 minus MBT) will be retained. The subsequent NAs (Its duration is MBT) will be deleted (see segments 4' and 5). If RTU module is online between two neighboring hours, the data processing software will obtain 1-hour data directly. In the case that RTU module is offline between two neighboring hours, the data processing software will scan the text file every 2 hours. Once 1-hour data are determined and detached, the software will scan next-hour data. Finally, these 1-hour data files will be packed automatically and sent to a prescribed email address regularly by the cloud server system.

4. Comparison with existing instrumentation systems

As mentioned above, two common instrumentation systems, the system composed of recording instrument and automatic memory card (e.g., Turnipseed *et al*. 2003) and the one consisting of recording instrument, radio transmitter and radio receiver (e.g., Zhang *et al*. 2008), are used for long-term field measurement in remote mountain areas. Here these are referred to as Systems 1 and 2. The proposed wireless system by authors is referred to as System 3, while the advanced wireless system developed by Otero *et al*. (2009) is referred to as System 4. Due to the similarity of the Systems 3 and 4, they will be compared later in detail.

The comparison for first three systems is summarized in Table 1. It shows that the proposed wireless transmission system based on GPRS has distinct advantages compared to first two systems, such as real-time transmission, low cost, no manual collection of data. It is also interesting to make a comparison between Systems 3 and 4. System 4 is mainly developed for a short-term wind field measurement with multi-sensors such as pressure sensors and anemometers. A laptop is used to collect the bulk data from multi-sensors and these data will be transmitted via WiFi or UMTS/HSPA/HSUPA network every 5 minutes. On the other hand, System 3 is proposed for the long-term wind field measurement using limited anemometers in remote areas. In this system, the laptop or computer is not considered in order to reduce the cost and minimize the power supply and maintenance. Significantly different from System 4, the data from the anemometer are transmitted directly by RTU module. Because these data have not been labeled with time and the transmission may be interrupted by bad network, the data treatment software is developed to reconstruct the original data from transmitted data. Note that such operation is not necessary for System 4.

Table 1 Comparison of different instrumentation systems

Traits	System 1	System 2	System 3
real time	no	yes	yes
total cost	low	high	low
manual data collection	yes	no	no
electric power supply	no need	need	no need

5. Application to field measurement

This newly-developed instrumentation system was deployed to collect wind data from the construction site of Puli Great Bridge at Yunnan Province of China. This bridge is located in a typical mountain valley area, as shown in Fig. 3.

The detailed implementation scheme is as follow:

1) Description of high-frequency anemometers. Two R.M. Young 81000 ultrasonic anemometers are used to collect the wind speed. The measurement range of the wind speed is from 0 to 40 m/s. The measurement accuracy of the wind speed is less than 3%. The sampling frequency of the anemometer is set to 4 Hz for sampling the high-frequency fluctuating wind.

2) Selection of RTU module. The RTU module of an industrial grade has been selected; this has high reliability and can work in the harsh environment. It also allows for ‘plug and play’, and is easy to use. The cache memory of this RTU module is 64 Kb. Fig. 4 shows RTU module used in the field.

3) Analysis of GPRS data traffic. The output format of data per second from an anemometer is shown in Fig. 5, where four rows represent the sampling frequency of 4 Hz and five columns stand for the wind speed, wind direction, elevation angle, sonic speed and temperature. It can be determined that the data flow rate from an anemometer is 1.125 Kbps. The transmission rates of RTU module and GPRS network are 10 Kbps and 56-116 Kbps, respectively. Hence, it can satisfy the demand of real-time transmission sufficiently. Note that MBT of RTU module is 7.585 minutes and all cached data (64 Kb) can be transmitted in 51.2 s. Also note that the total data traffic per month is about 360 Mb. Therefore, the data package of 500 Mb for each mobile phone card has been ordered to satisfy the data traffic demand.

4) Configuration of power supply system. The rated power of each ultrasonic anemometer and RTU module is about 2.5 and 1.5 watts, respectively. Therefore, the total power of the instrumentation system is less than 8 watts. On the other hand, this solar power system contains two 40-watt solar panels and a 120AH, 12V lead-acid battery. Therefore, this solar power supply system can not only provide the electricity to the anemometers and RTU modules but also generate extra electricity to recharge the battery in a normal situation. Besides, the lead-acid battery can work continuously for 120 hours theoretically in the case of no sunshine.

5) Field installation of the whole system. Two solar panels are shown in Fig. 6(a). A waterproof box with excellent heat dispersion was customized for enclosing the RTU modules, solar panel controller and lead-acid battery, as shown in Fig. 6(b). Fig. 6(c) shows the layout of two ultrasonic anemometers on the tower. These anemometers were mounted at the heights of 30 m and 50 m above the ground level, respectively. The field installation of the power supply system and data transmission unit is shown in Fig. 6(d). Clearly, the developed instrumentation system is convenient to be mounted.

Fig. 3 Aerial view of construction site of Puli Great Bridge

Fig. 4 RTU modules used in the field

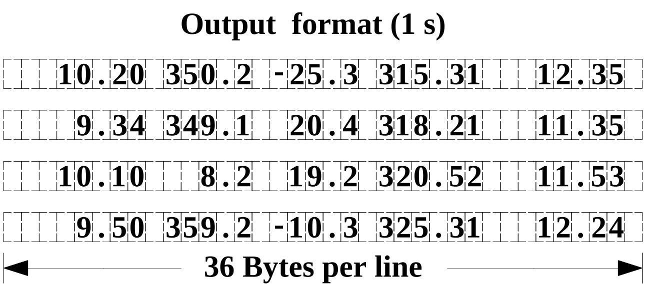
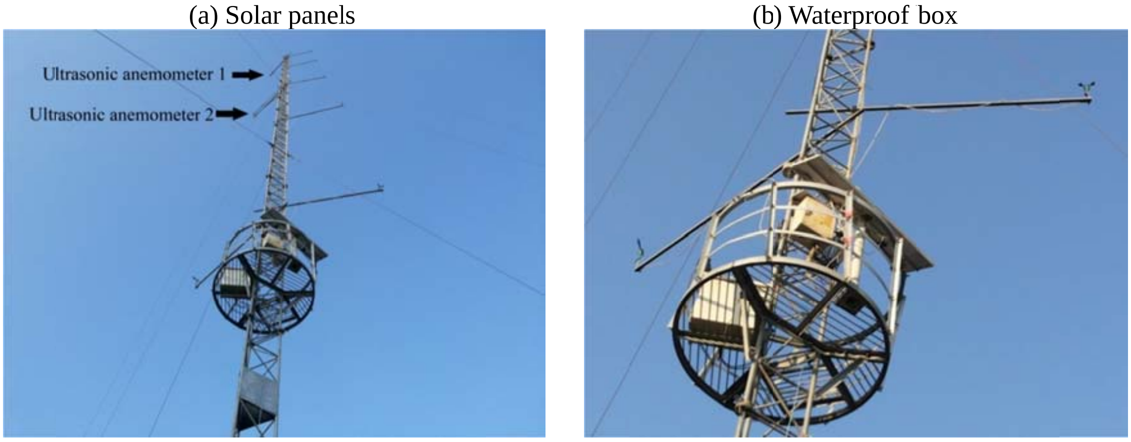


Fig. 5 Output format of data from an anemometer

(a) Solar panels (b) Waterproof box



(c) Layout of two ultrasonic anemometers (d) Close up to the system

Fig. 6 Photos of field installation of proposed system

6) Allocation of cloud server, software and email system. A cloud server of China Telecom with 80G hard disk and 2G internal memory is adopted to receive and process data. Meanwhile, the TCP data receiving/processing software was installed on this server. After the text file of 1-hour data has been generated, it is sent to the prescribed email regularly.

7) Development of a web-based Graphical User Interface (GUI). In order to conveniently monitor the real-time data, a web-based GUI has been developed, as shown in Fig. 7. The blue tabs in the middle of Fig. 7(a) illustrate the real-time measurement data. The red flags in Fig. 7(b) show the locations of the ultrasonic anemometers on the digital map.

As mentioned previously, transmitted data may be lost due to a bad GPRS network. Table 2 summarizes data loss rates from 01/26/2014 to 02/03/2014. It indicates that the averaged data loss rate per day is less than 0.07%. Roughly, it is equivalent to a 1-minute data loss per day. Also data missing is random. Therefore, data missing has no influence on the quality of the field measurements and the proposed system is reliable. In addition to missing data, the accuracy via this proposed system is also of concern. The comparison with wired connection was conducted in a wind tunnel before the field installation. Based on two sets of 24-hour wind data, it is found that data from the wireless transmission agreed with those from wired connection within 0.1%.

(a) Real-time data display (b) Anemometer locations on map

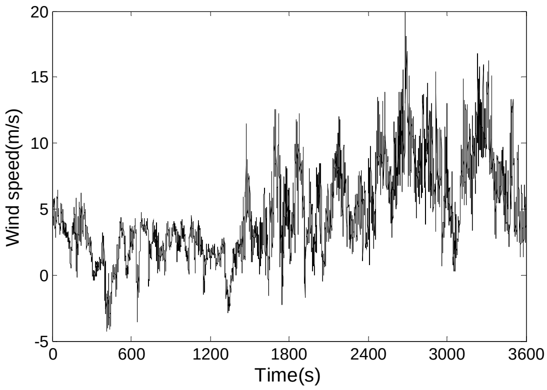
Fig. 7 Web-based Graphical User Interface

Table 2 Data loss rates

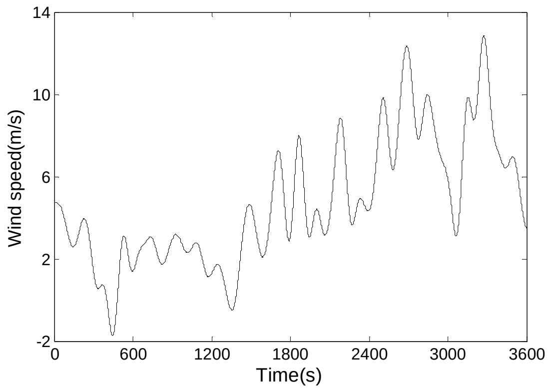
Date	Data loss rate (%)		Weather
	RTU 1	RTU 2	
26 Jan 2014	0.07	0.05	Rain
27 Jan 2014	0.06	0.05	Rain
28 Jan 2014	0.04	0.03	Sun
29 Jan 2014	0.13	0.05	Sun
30 Jan 2014	0.02	0.03	Sun
31 Jan 2014	0.03	0.07	Sun
1 Feb 2014	0.04	0.06	Snow
2 Feb 2014	0.04	0.07	Snow
3 Feb 2014	0.05	0.08	Sun

6. Selected samples of measured data

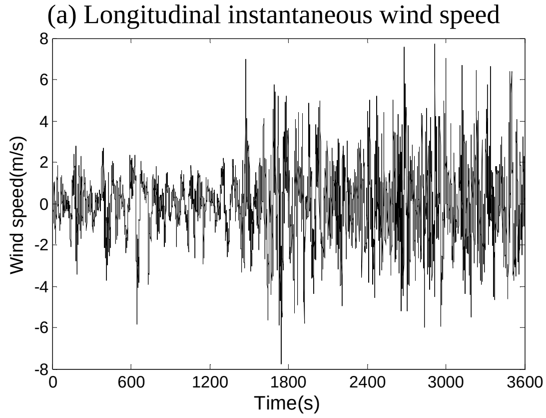
The installation of the instrumentation system in the field has been accomplished at the end of 2013. Samples of 1-hour wind speed and wind direction are chosen to illustrate the characteristics of strong winds in mountain valley area. The longitudinal instantaneous wind speed is shown in Fig. 8(a), which indicates that the maximum instantaneous wind speed can reach to 20 m/s. In order to extract the time-varying mean wind speed, the wavelet decomposition (level 8 and db20) is adopted. The corresponding time-varying mean and fluctuation of the wind speed are illustrated in Figs. 8(b) and 8(c). The sample clearly demonstrates that strong winds in mountain area contain remarkable nonstationarity. Fig. 8(d) displays that the wind directions mainly vary from the south to west.



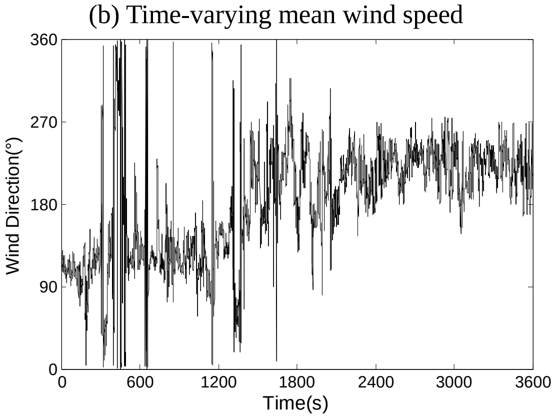
(a) Longitudinal instantaneous wind speed



(b) Time-varying mean wind speed



(c) Fluctuating wind speed



(d) Instantaneous wind direction

Fig. 8 Selected samples of measured wind speed

7. Conclusions

High-frequency anemometers such as ultrasonic anemometers are extensively used to measure fluctuating winds in the field. Current data collection instrumentation systems may not be suitable for the field measurement of strong winds in remote areas. In this study, a wireless high-frequency instrumentation system for field measurement was developed. The architecture of the proposed system, data transmission and treatment, main features and practical application are presented in this paper. Evidently, a proposed wireless transmission system based on GPRS had distinct features, such as real-time transmission, lower cost, and no manual collection of data. Also, a laptop or computer was avoided in the proposed system in order to reduce the cost and minimize the power supply and maintenance. Although this system was originally developed for the mountain area, it could be used for island or coastal areas, and hazardous structures such as ultra-voltage transmission tower. In addition, wind pressure and other data can be collected in the similar way.

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