The development and tests of remote data acquisition and transmission system on civil engineering structural vibration

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ABSTRACT
Aiming at the difficult problem of on-site real-time vibration responses monitoring and remote data transmission of the civil engineering structures, based on LabVIEW a remote data acquisition and transmission system is designed. In the system NI data acquisition card and DataSocket protocol of the LabVIEW software platform are used to realize data collection, remote transmission and control. That is, the civil engineering structural vibration responses can be monitored through internet at anytime and anywhere. The vibration parameters of a cantilever beam is detected and transmitted in real-time by using this system. The test parameter values are compared with the theoretical calculating value. The results show that relative to the traditional cable measurement and wireless short-range measurement, this system can effectively realize the remote real-time data acquisition, transmission, display, storage and control. Furthermore, the accuracy of data transmission is high. On the other hand, the system is easy to be built and maintained.

1. Introduction
In the process of health monitoring of civil engineering structures, the structural state parameters often cannot be monitored in real-time because of the harsh condition around or/and the performance limitation of traditional measurement devices. Sometimes it may lead to irreversible consequence because the site’s information cannot be timely feedback to technicians. Obviously, this situation cannot meet the needs of the times.

At present, many well-known scholars in the health monitoring of structural vibration are doing a lot of research. Xu and Wu (2007) proposed a damage detection strategy based on acceleration responses’ energy. Numerical analysis results showed that the acceleration responses’ energy-based damage detection strategy has not only accurate damage location ability but also excellent damage quantification ability and anti-noise pollution ability. The environmental excitation incomplete strain mode method is a method of damage detection for space truss structures, which is effective in the location and quantification of damages for single-member and multimember damages (Xu and Wu 2012; Xu, Shen, and Guo 2003). Yu and Zhao (2013) built wireless experimental systems of Polyvinylidene Fluoride sensor for structural local monitoring on a bridge model and beam. Siddheswar and Biplab (2015) presented the design of sensor node for wireless sensor network dedicated for structural health-monitoring application based on Cortex M3 ARM controller. Gulizzi and Rizzo (2015) proposed a structural health-monitoring paradigm based on the simultaneous use of ultrasounds and electromechanical impedance to monitor waveguides. Chowdhry and Shaikh (2015) deployed a wireless sensor network on a bridge model to analyze the vibration response of intact and damage bridge model. Pan and Azimi (2017) proposed a new vibration-based mechanical learning method for SHM system state evaluation and damage detection, which could map damage features in a high dimensional feature space. Li and Ou (2006) put forward a health-monitoring system of cable-stayed bridge, which was composed of sensor subsystem, data acquisition and transmission subsystem, structural analysis and data management subsystem. And harmonious operation of different systems needed to be realized through system integration technology. But with the emergence and development of virtual instrument and computer network, the combination of virtual instrument and Internet technology provided a better implementation platform for the network virtual instrument, remote measurement and control of the industrial field (Jia and Zhang 2009; Zhou et al. 2018; Xu et al. 2019).

A remote data acquisition and transmission system for the civil engineering structural health monitoring is introduced and realized in this paper depended on NI’s data acquisition card and DataSocket technology using the LabVIEW software. The system includes remote data acquisition, transmission, storage, display...
and control. Through vibration acceleration acquisition test on a cantilever beam, the corresponding performance parameters are obtained and compared with the theoretical calculating values. The results show that the system can accurately measure the acceleration responses, and transmit data to the remote client for processing and storing in real-time. Furthermore, the accuracy of data transmission is high. On the other hand, the system is easy to be built and maintained.

2. The design of whole system structure

In this paper, the system consists of the hardware part and the software part, of which the software part is the core. The hardware part mainly consists of the acceleration sensor, charge amplifier, PXI data acquisition card, NI real-time controller and PC. The software part is developed based on LabVIEW2012.

The functions of the software include data acquisition, data processing, display, storage, remote transmission and control. First, the physical signals which measured by the sensor are converted into electric signals, and then the electrical signals are filtered and amplified through a charge amplifier and transmitted to the server host software by the data acquisition card. After data acquisition is finished, the data are transferred to the DataSocket server by DataSocket protocol, and its URL path is configured to identify different physical quantities. According to the path of URL configured, the client can read data from DataSocket server. After data processing, the collected data can be displayed in real-time by using waveform, and also saved in the file whose name is data acquisition time simultaneously. The data are saved as ASCII format text file, and can be analyzed by using the other software. On the other hand, the client can control the server through DataSocket server. The structural block diagram of the system is shown in Figure 1.

2.1. The hardware design

In this paper, the hardware part of the system mainly consists of acceleration sensor, charge amplifier, PXI data acquisition card, NI real-time controller and PC. The system can complete the data collection of complex system in harsh environment, and transmit the data to the client through network (WAN or LAN).

The system adopts PXie-8133 real-time controller of National Instruments (NI) as server, which is equipped with Windows 7 operating system and two networks interface. It can be connected with the client on the LAN or WAN through the cable. The standard TCP/IP protocol is used as the network communication protocol. PXie-6363 series acquisition card is used as data acquisition card in the system. It has 32 analog input channels, 4 analog outputs and 16 bits resolution. It can realize the high speed and real-time data acquisition. CA-YD-103 85775 series piezoelectric sensor produced by Jiangsu Lianneng Company is used as acceleration sensor, and the YE5853 series charge amplifier is adopted to amplify and filter the charge output from acceleration sensor. The client adopts the PC with the client software.

2.2. The software design

2.2.1. The realization of data acquisition

There are two kinds of data acquisition programming function in LabVIEW: traditional DAQ and DAQmx. Because the sampling frequency of the DAQmx is 10 times than that of traditional DAQ, DAQmx is used generally in the high-speed data acquisition (Yan and Yang 2013). In this system, DAQmx is also adopted in this program. The part of data acquisition program is shown in Figure 2.

Data collection uses the DAQmx acquisition module of LabVIEW, its acquisition speed is fast and stable, and it is also compatible with most acquisition card. The data acquisition program is mainly composed of AI configuration, AI start acquisition, AI read data, and AI clear to complete the task. After completing the data acquisition, the acquisition tasks will be clear. The program should pay attention to several key parameters before operation:

(1) Selecting the correct acquisition channels and the measurement mode.
(2) According to Nyquist sampling theorem, sampling rate is more than twice the frequency of signal measurement. The practical measurements should be 5 ~ 10 times than the theoretical value.

![Figure 1. The structural block diagram of the system.](image-url)
(3) It should set the true number of DAQmx read function to read data from the cache, and set read number according to the current sampling rate.

2.2.2. The realization of remote data transmission and control function

There are many ways in LabVIEW software to realize remote transmission, such as TCP/IP protocol, DataSocket protocol, UDP protocol, Shared variables, and so on. Integrating the characteristics of the above methods, the system has chosen the DataSocket protocol technology as the transmission method of the system.

DataSocket technology is the network communication technology for measurement and control proposed by NI Company. DataSocket technology is based on Microsoft’s COM and ActiveX technology, it is high encapsulation of TCP/IP protocol for measurement and automation applications to share and release real-time data. Thus it can simplify the writing process of communication program and improve the efficiency of programming (Rong and Xu 2005).

The client/server communication mode is used in the design of program. DataSocket function library in LabVIEW contains the Read and Write function, and chooses DSTP as the basic agreement. To the server program, the write function of DataSocket is configured first, and URL address is filled in correctly. Through write function of DataSocket, the various data information which need to be transmitted will be marked to write in the DataSocket Server by the network. While to the client program, through the URL address in the Server, the data marked just now are read from the DataSocket Server by read DataSocket function. The work time delay is only influenced by the current network conditions.

On the contrary, in order to realize the function of remote control, the client’s control commands are put into DataSocket Server via write DataSocket function, then the Server will read control commands from DataSocket Server by read DataSocket function. Choosing the DataSocket agreement in data-binding properties of the control, the setting of the control way is one of the read-only/write-only/read and write, and fill in the correct URL address. One of the controls changes, another will also synchronous changes accordingly. Thus it can realize the control of client to server. In the process of whole control and transmission, DataSocket Server is needed open. The design of the system software is shown in Figure 3.

2.3. The theoretical model of the free vibration of cantilever beam

The cantilever beam is a continuous elastic body and has an unlimited number of degrees of freedom, namely an unlimited number of natural frequency and main vibration mode. The vibration can be expressed as superposition of an infinite number of principal modal. For the vibration of the beam body, only the deformation caused by the bending is considered, regardless of the deformation caused by the shear and the influence of the moment of inertia. This mechanical analysis model is called the Euler-Berner beam. When the mass of the cantilever beam is relatively light and the moment of inertia is small in transverse vibration, the resulting shear deformation is negligible. Therefore, the influence of shear deformation and moment of inertia on the beam can be
ignored, only its bending deformation can be considered, and the Euler-Berner beam mechanical analysis model mentioned above can be established (Xu and Lu 2011; Gu et al. 2018). Combined with the condition of cantilever beam which one is the fixed and another is free. The cantilever beam is simplified as a free vibration of single degree of freedom. The theory calculation formula of the angular frequency of the cantilever beam is:

\[ \omega_n = \sqrt{\frac{K}{M}} = \sqrt{\frac{3EI}{M \cdot L^3}} \]  

(1)

So the natural frequency, \( f \), is:

\[ f = \frac{\omega_n}{2\pi} \]  

(2)

where \( K \) and \( E \) are respectively the stiffness and the elastic modulus; \( M \) is the quality of the mass block of the free end; \( L \) is the length of the cantilever beam; \( I = bh^3/12 \), which is the moment of inertia, where \( b \) and \( h \) are respectively the width and height of the cantilever beam.

Actually, when the cantilever beam is excited to generate free vibration, due to the presence of damping, the amplitude of its free end appears the exponential decay waveforms (Jing, Lang, and Billings 2008a, 2008b). So according to the solution of the motion equation of a damped free vibration of a single degree of freedom in structural mechanics, the analytic solution for the displacement of the free end of the cantilever beam:

\[ u(t) = e^{-\zeta \omega_n t} \left[ u(0) \cos \omega_d t - \frac{\dot{u}(0) + \zeta \omega_d u(0)}{\omega_d} \sin \omega_d t \right] \]

(3)

\[ \text{Figure 3. The flow chart of the system software.} \]
where $\xi$ is the damping ratio which can be obtained by experiment curve; $u(0)$ and $\dot{u}(0)$ are respectively the initial displacement and velocity of the free end of the cantilever beam (The displacement is the distance from the free end of the cantilever beam to the equilibrium position); the natural angular frequency of the damping of the cantilever beam is $\omega_D$ given by

$$\omega_D = \sqrt{1 - \xi^2} \approx \omega_n.$$ 

### 3. The experiment of system test

The acceleration responses of the damped free vibration of cantilever beam under the external force are collected by using the designed system. The cantilever beam is made of 60Si2Mn spring steel whose Poisson’s ratio is $0.26 \sim 0.32$, and elastic modulus is $E = 206$ GPa, the width is $b = 20$ mm, the height is $h = 2$ mm, the length is $L = 210$ mm, the mass of the mass block of the free end is $M = 165$ g. Client and the Server software are respectively installed in the PC and NI real-time controller. They will be connected through the network. The acceleration sensor is fixed on the free end of the cantilever beam, and then the free end of the cantilever beam is pressed down away from the equilibrium position for 1 cm to let the cantilever beam do the damped free vibration. **Figure 4** shows the whole test system. **Figure 5** shows the acceleration curve and the frequency spectrum of the cantilever beam test system.

According to the test results of the cantilever beam, the damping ratio, $\xi$, is 0.0045; the measured natural frequency of the cantilever beam, $f$, is 11.694 Hz. And according to Equations (1) and (2), the theoretical value of the angular frequency, $\omega_n$, is 73.433 rad/s; the theoretical value of the natural frequency, $f$, is 11.687 Hz. The error is 0.007 Hz, and which is 0.06 of the theoretical value.

Furthermore, the initial condition of the cantilever beam system, including the initial displacement and velocity of the free end of the cantilever beam, is put into Equation (3) to get the displacement and acceleration response of the theoretical solution respectively as

$$u(t) = e^{-0.3304 t} [0.01 \cos 73.433 t + 0.000045 \sin 73.433 t]$$

$$\ddot{u}(t) = e^{-0.3304 t} [0.2426 \sin 73.433 t - 53.92 \cos 73.433 t]$$

The comparison of acceleration responses between the theory curve and the measured curve is shown in **Figure 6**. It can be seen that the theoretical and measured values of the maximum acceleration are 26.74 m/s$^2$ and 27.99 m/s, and the error rate is 4.67%. The test results show that can effectively realize the remote real-time data acquisition, transmission and display the vibration characteristics of the cantilever system generated under external force.

### 4. Conclusions

The remote data acquisition and transmission system for the civil engineering structural health monitoring is designed based on LabVIEW in this paper. The vibration parameters of a cantilever beam is detected and transmitted in real-time by using this system. The test
parameters value are compared with the theoretical calculating value. The results show that relative to the traditional cable measurement and wireless short range measurement, this system can effectively realize the remote real-time data acquisition, transmission, display and storage, furthermore, the accuracy of data transmission is high. On the other hand, the system is easy to be built and maintained.

Figure 5. The measured acceleration curve and the frequency spectrum of the cantilever beam. (a). The acceleration curve of the cantilever beam. (b). The acceleration frequency spectrogram.

Figure 6. The comparison of acceleration responses between the theory curve and the measured curve.
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