Acta Technica 62 No. 2A/2017, 495–508

Design and research of wireless vibration signal detecting system for SCM and Bluetooth transmission

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Abstract. Sensor signal is transmitted by cable or optional fiber in the traditional vibration detection. But on an occasion with different wiring arrangement, wireless method should be taken to transmit the signal. Bluetooth technology is selected as a plan for vibration data transmission, and wireless vibration signal detecting system is also designed that is based on SCM and Bluetooth transmission. In hardware design, STC microcontroller is adopted as micro-control center for signal acquisition. Vibration signal is first picked up by sensor, then enlarged and filtered the circuit to transmit to A/D converter. Finally A/D converter is controlled by vibration signal with SCM to finish the acquisition of vibration signal. Digitized signal is made a wireless launch through Bluetooth protocol communication. At the receiving end, Bluetooth transmits the signal that is accepted by the USB interface circuit to the PC computer; in the software design, C programming language is first used to finish the design that is made by SCM to signal acquisition and transmission procedure. And LabVIEW development platform is chosen to research and develop human-computer interaction interface, which can achieve the control of SCM and real-time display receiving data, and the make an analysis about it; at last, the reliability and stability of the wireless vibration signal detecting system is verified by building test experimental platform. With the vibration frequency of vibrostand increased, the relative error of vibration frequency gained from wireless vibration detecting system is also increased, but the relative error is less than 5 %. Thus, the designed wireless vibration detecting system, with higher reliability and stability, basically satisfies the used demand.

Key words. SCM, Bluetooth wireless communication technology, vibration signal, Lab VIEW.

1. Introduction

Generally speaking, the traditional vibration detection method is that the sensor placed at test points and the exported signal of sensor is transmitted to data processing center through relevant cable or optical fiber, then the gained data is analyzed and processed to achieve the detection to the vibration [1–3]. Although

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the traditional vibration detection system is more mature with a wide application range, some inadequacies of this method are still found in the functional application. For example, in the case of the vibration detection in some areas such as rotation components, explosion, nuclear power plant and so on, the vibration signal gained by sensor is hard to be transferred by cable [4, 5].

Besides, what traditional medical facility does during vibration measurement of physiological parameters is, that it transmits the physiological signal to medical facility by cable [6]. This wired method not only makes people nervous and uncomfortable, but also limits people's activities. When people are not in a natural state, human health condition cannot be truly reflected by the gained physiological parameters [7]. For the wired method transmits signal, wireless method is adopted to transmit signal can not only leave out the waste-time-and-energy cable arrangement, but also can resolve the problem that the cable cannot be arranged in the spot, and can move flexibly and conveniently [8]. A wireless vibration sensing system with small size, low cost and high practicability is expected to be developed

2. Literature review

According to the length of wireless transmission distance, it can be classified into two kinds of transmissions: short distance and long distance [9]. At present, there mainly have several popular short distance wireless transmission technologies: infrared, Zig Bee, WLAN, Bluetooth, UWB, FR and other wireless transmission technologies [10, 11]. Infrared transmittal rate is rather higher, but its transmission distance is short (1–3 m) and its angle is limited [12]. Zig Bee not only has many advantages such as low power dissipation and cost, but it also can make a wireless transmission with bi-directional data [13]. Modules needed by WLAN are expensive, which strictly limits its application range. While transmission rate of Bluetooth technology is higher than Bee and its cost is lower than WLAN, so Bluetooth is selected as a plan for vibration data wireless transmission [14, 15].

Wireless detection technology can make up the deficiencies of traditional wired detection technology, especially on some occasions like inconveniently using cable or not using cable transmission, which remarkably show wireless transmission's advantages. According to abroad and domestic researches, wireless technology is mainly applied to industrial control and environmental monitoring, and most of the monitoring objectives are temperature, humidity and illumination intensity in the environment and other slowly changing signals. While for the vibration wireless detection is mainly in low-frequency vibration of bridges, buildings, ocean platforms and other large-scale architectures. With more and more concern about health, wireless technology has a wide prospect in medical treatment and health. Therefore, a wireless vibration detection system based on Bluetooth transmission is designed.

3. Research methods

3.1. Hardware design

Bluetooth wireless communication technology is adopted and a plan is put forward based on Bluetooth transmission for wireless vibration detection system. The whole structure is shown in the following Fig. 1.

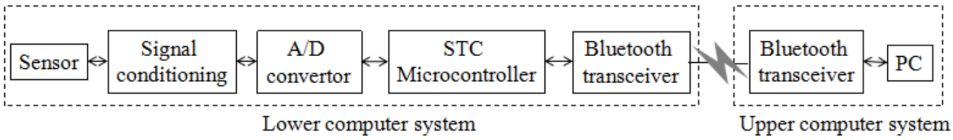

Fig. 1. Whole block diagram of system hardware

From Fig. 1, this wireless vibration detection system consists of upper computer system and lower computer system. The upper computer system hardware is mainly composed of PC computer and Bluetooth. HC05 Bluetooth module is adopted in this research. PC computer is linked with Bluetooth by USB serial interface circuit. And based on the UI of wireless vibration detection system that is designed by Lab VIEW platform in the upper computer system, according to the UI, real-time display and vibration data's storage of vibration signal not only can be achieved, but also the Fourier transform of vibration signal can be analyzed and also can achieve the control of the lower computer system.

The lower computer system mainly consists of SCM, signal processing circuit and Bluetooth and others. So acquisition and wireless dispatch of vibration signal can be achieved.

3.1.1. Design of vibration signal acquisition circuit. Signal processing circuit can enlarge the small signal exported by sensor and have smoothing function. STC89C52 SCM is adopted as microcontroller. According to the design of its peripheral circuit and the software design, A/D convertor and data acquisition can be achieved to control. And then the collected vibration data is transmitted to Bluetooth by UART. Finally, vibration signal is made a wireless launch by Bluetooth.

SCM peripheral circuit generally includes four parts: SCM chip, clock circuit, reset circuit and power source, which means the smallest peripheral configuration can make SCM work normally. Power source adopts 5V direct-current main. Circuit diagram is shown in the following Fig. 2.

Most of detection systems' microcontroller only can receive and process digital signals. While the commonly used output signals of sensor is generally the analog signals. So before inputting these analog signals to the microcontroller, it should be converted into digital signals by analog-digital conversion chip. This system adopts ADC0804 chip. Because analog-digital conversion chip cannot finish the work by itself, it should cooperate with microcontroller to use. Its schematic circuit diagram is shown in the following Fig. 3.

The signal outputted by piezoelectric acceleration sensor is generally too weak.

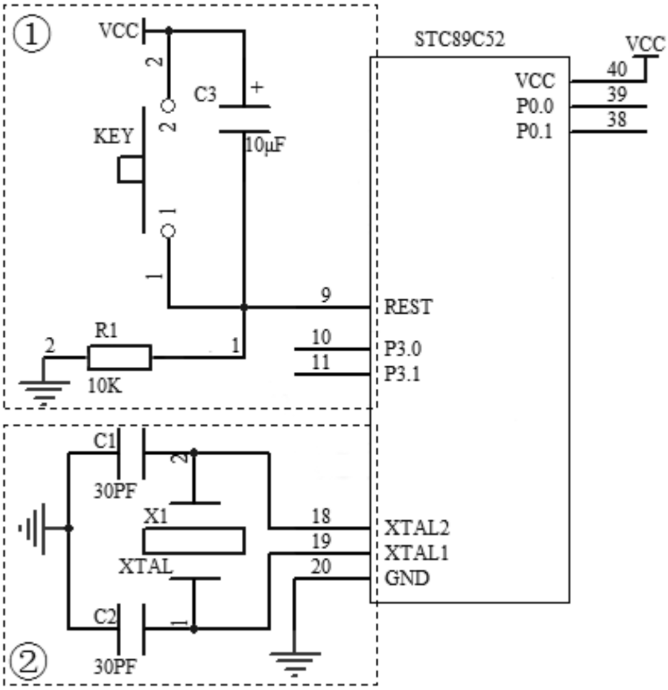

Fig. 2. SCM schematic diagram (automatic and manual reset circuit in imaginary line region (1), SCM clock circuit in imaginary line region (2); P3.0 is the RXD serial input interface, P3.1 is the TXD serial output interface)

In order to improve the whole measuring system's accuracy and measurement accuracy, the outputted vibration signal of sensor needs to be amplified and processed. Vibration signal's conditions mainly contain two parts: smoothing and amplification. The design of smoothing circuit can improve the SNR in the whole measuring system. Because the designed wireless vibration detection system is for low-frequency vibration's detection in this research, no-source LPF circuit is designed, which is shown in Fig. 4.

The output signal of piezoelectric acceleration sensor has two measuring circuits: the first one is voltage amplifier circuit, while another one is electric charge amplifying circuit. The output voltage of this electric charge amplifying circuit is only proportional to its inputted quantity of electric charge, so its largest advantage is make the piezoelectric acceleration sensor's sensitivity not influenced by the circumscribed cable. Its operating circuit is shown in Fig. 5.

In Fig. 5, Q is the output electric charge quantity of piezoelectric acceleration sensor, (-A) stands for reverse input end of operational amplifier, and R_{f} is the feedback resistance. In this circuit, its positive end is connected to ground, and the output voltage is

$$U_{\mathrm{o}} \approx U = -\frac{Q}{C_{\mathrm{f}}}\,. \tag{1}$$

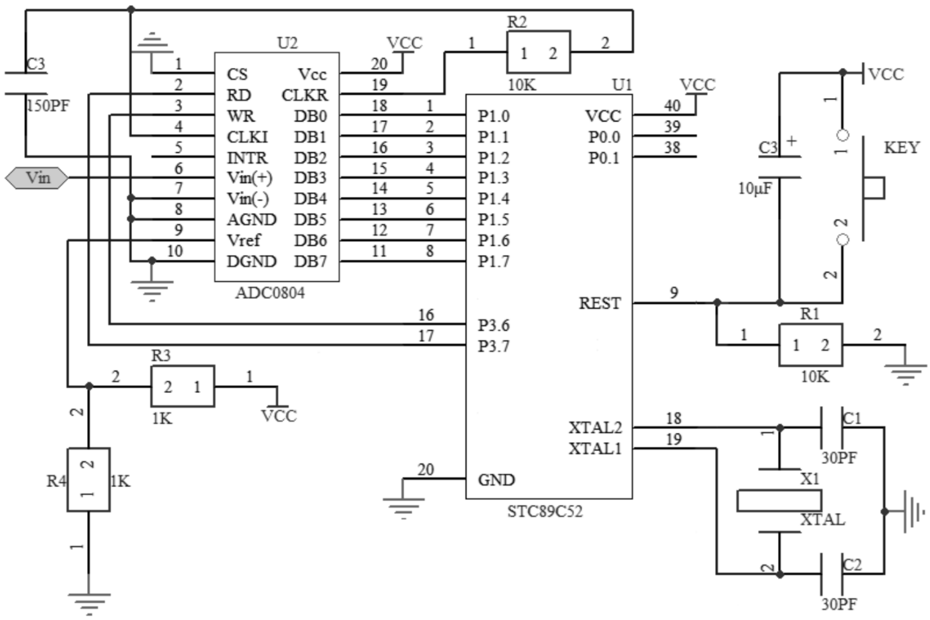

Fig. 3. Working schematic circuit diagram of ADC chip

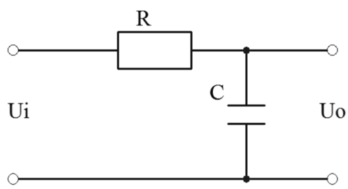

Fig. 4. No-source LPF circuit

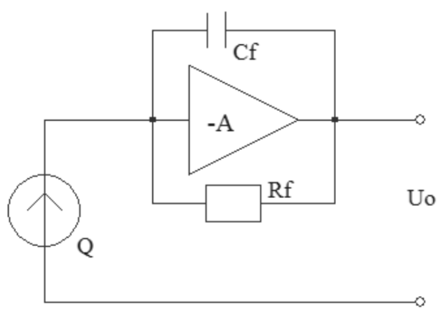

Fig. 5. Electric charge amplifying circuit

In this formula, U is the both-end voltages of feedback capacitance C_{f}, U_{o} is the output voltage of electric charge amplifying circuit. High frequency upper limit of electric charge amplifying circuit generally can reach 180 kHz, while its low frequency lower limit f_L depends on the feedback capacitance and feedback resistance:

$$f_L = \frac{1}{2\pi R_f C_f}\,. \tag{2}$$

From formula (2), low frequency lower limit of electric charge amplifying circuit is inversely proportional to time constant $R_f C_f$, and f_L can reach $10^{-1} \sim 10^{-4}$ Hz (quasi state).

3.1.2. Bluetooth module design. All the functional parts of Bluetooth can be made as a combinational design in the Bluetooth technology's development process. Because of limited development time, Bluetooth module usually contains an integrated RF transceiver, baseband controller, link supervisor and HCI to a chip.

According to operating mode, Bluetooth module can be classified into two parts: master Bluetooth and slave Bluetooth. Master Bluetooth can search for surrounding slave Bluetooth facilities and request an initiation, but it cannot be searched by other mater Bluetooth. Slave Bluetooth only can be searched and connected. And it can be matched with master Bluetooth, Bluetooth adapters or computers, mobiles and other electronic equipment with Bluetooth function. After matched successfully, serial port communication is on operation. HC05 Bluetooth module is adopted, that is a principal and subordinate Bluetooth module. This module can achieve Bluetooth communication and transmission function only needs little peripheral circuit. Peripheral schematic circuit diagram of HC05 Bluetooth module is shown in Fig. 6.

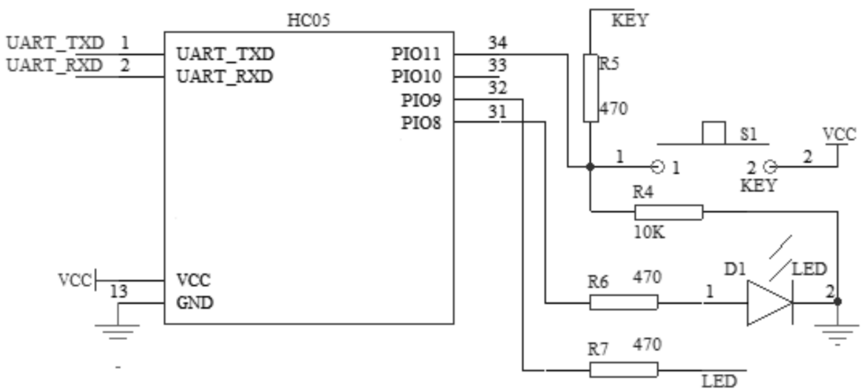

Fig. 6. Peripheral schematic circuit diagram of Bluetooth module

From Fig. 6, SCM's four pins, RXD, TXD, VCC and GND should be linked accordingly with Bluetooth module's four pins, UART_TXD, UART_RXD, VCC and GND. Only doing this, the Bluetooth module can work normally and complete the data's wireless transmission. Besides, the Bluetooth needs testing and other parameters need setting, so the design of Bluetooth wireless transmission can be finished.

4. Software design

Software programming is classified into two parts: low computer programming and upper computer programming.

4.1. Low computer programming design

The whole program compilation and object code generation of low computer are finished in the Keil *upmu*Vision3 development environment. And low computer programming is a software design for SCM. MD is used in the program development process. And first, subprograms of all the modules are designed, and then main program is used to adjust all the module subprograms. Subprogram included delay, suspend, A/D converter, serial port communication and other programs. The design of signal acquisition program is represented in the following.

Vibration signal's acquisition process is achieved by signal acquisition by means of SCM controlling the A/D converter chip. In the acquisition process, A/D is first started, and then waits for whether A/D has been converted. At last, SCM reads the data that A/D converted. In this programming, sequential working drawing of ADC0804 analog-digital conversion chip needs knowing and this chip's normal working can be achieved according to the program adapted by sequential working drawing. Figure 7 is the ADC0804 chip's working sequence chart.

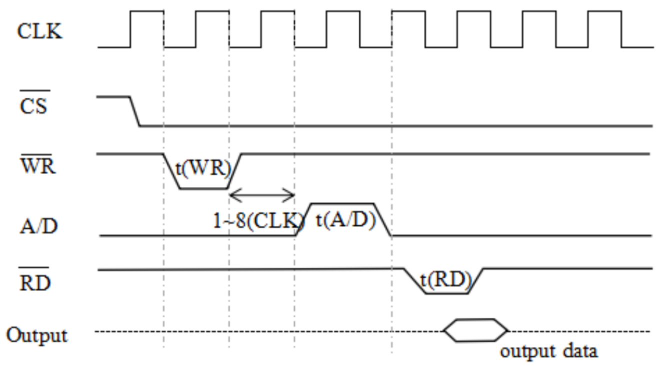

Fig. 7. ADC0804 chip's working sequence chart

According to the above sequence chart, signal acquisition programs are as follows:
CS = 0; WR = 1; _nop_(); WR = 0; _nop_(); WR = 1; P1 = Oxff ; RD = 1; _nop_(); RD = 0; _nop_(); TEMP = P1:

4.2. Upper computer programming design

Program adapted by Lab VIEW,Lab VIEW, is chosen and used for interface development, that includes front panel and program chart. Front panel is also called UI, which is mainly applied to control and display. In the front panel's programming environment, there are two kinds of controls: input control and display control. Input control can set parameters and manipulate data. Display control can display measured data in real time.

As UI of wireless vibration detection system, upper computer program has many functions in the whole process of wireless vibration detection. Its functional block diagram is shown in Fig. 8.

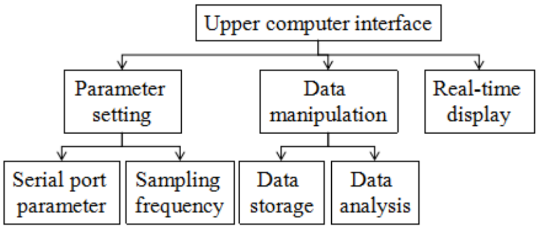

Fig. 8. Functional block diagram of upper computer interface

According to Fig. 8, upper computer programming design is dividing the whole upper computer into different modules and then makes an adaption to those different modules. Finally, the adaption work of the whole program. Figure 9 is the program chart of the whole upper computer programming design.

Low computer can be controlled by manipulating the upper computer's UI. At the same time, using this interface not only can achieve storage and real-time display of RXD, but also can display frequency spectrum curve after making an FFT analysis about vibration signal. It is convenient for researchers to intuitively know the vibration information.

5. Experiment and result analysis

5.1. Vibration test platform building

A vibration test platform is built to verify whether the wireless vibration detection system can normally perform its functions. The structure diagram of the whole test platform is shown in Fig. 10.

In this test experiment, first, vibrostand's vibration signal is picked up through piezoelectric acceleration sensor and converted as electric signal. Then electric signal outputted by sensor is enlarged and smoothed. After it is converted as digital signal by A/D convertor and stored in SCM to fulfill the acquisition of vibration signal. Through UART, SCM transmits the vibration signal form slave Bluetooth module to master Bluetooth module and then completes wireless launch of vibration signal.

Finally, master Bluetooth module is controlled by upper computer UI in the PC computer, which can achieve vibration signal reception wirelessly launched by low computer and store the received vibration signal and display it on the UI. In the meanwhile, vibration signal van be analyzed with Fourier transformation by using upper computer UI, and then display its frequency spectrum curve on the UI.

After the vibration test platform finished, it can test the designed wireless vibration detection system's function. vibrostand's vibration can be tested by using the existing piezoelectric acceleration sensor in the laboratory and the researched

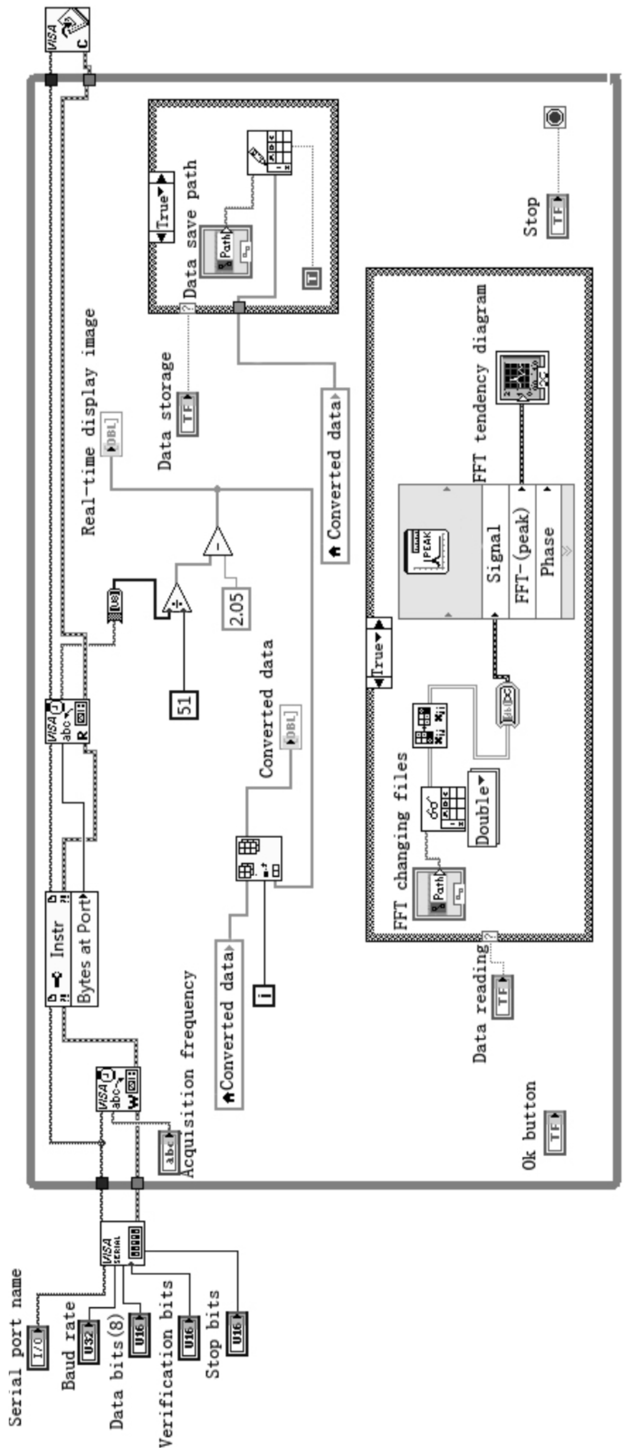

Fig. 9. Whole block diagram of upper computer program

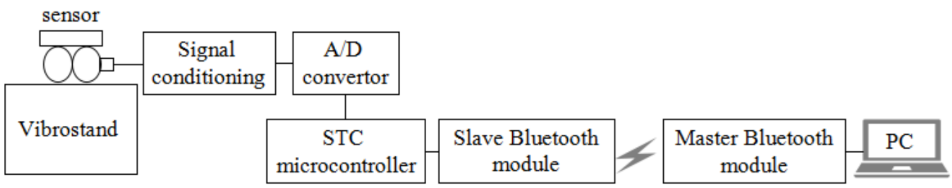

Fig. 10. Block diagram of vibration test platform

wireless vibration detection system, which can verify the reliability and feasibility of the system.

6. Experimental result and analysis

Figure 11 is the real-time display image where 10 Hz sinusoidal vibration detection is derived from the system's upper computer interface to the vibrostand.

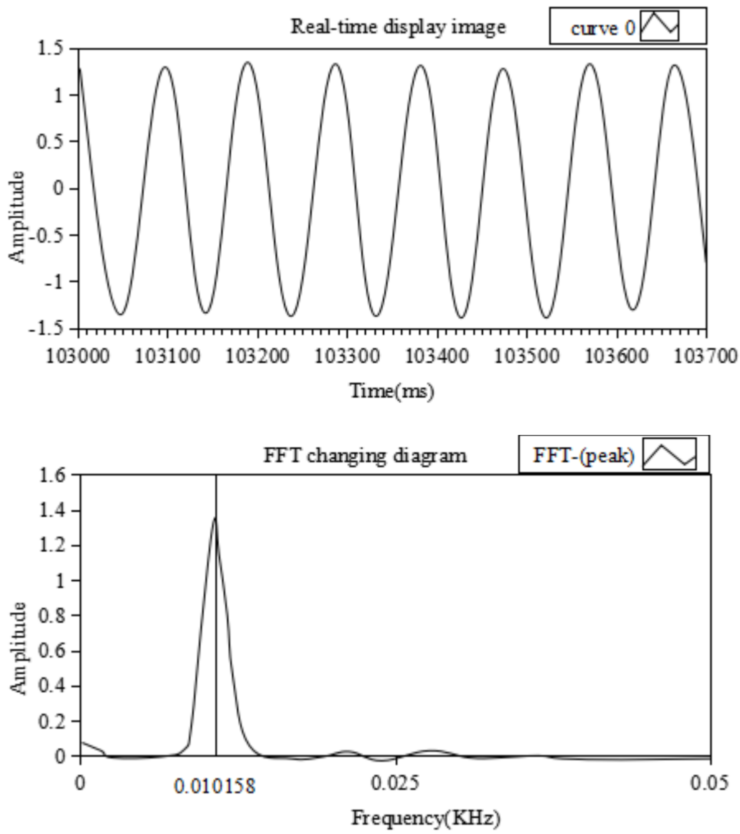

Fig. 11. 10 Hz testing result of vibration signal: up–time domain diagram, bottom–spectrogram

On the upper computer interface, vibration's real-time condition can be observed. Its upper part is the time domain waveform of vibration signal. Its bottom part is the spectrogram of vibration signal being quickly transferred to FFT. According to this spectrogram, vibration frequency can be intuitively watched. From FFT changing diagram, the wireless vibration detection result is: vibration signal frequency $f = 10.158\,\text{Hz}$. Compared with true value, its relative error is $1.580\,\%$.

In order to fully test the feasibility and reliability of the designed wireless vibration detection system, sinusoidal vibrations of 50 Hz and 100 Hz vibration frequency are respectively tested in the following diagrams. And their vibration detection results are shown in the figure Fig. 12 and 13.

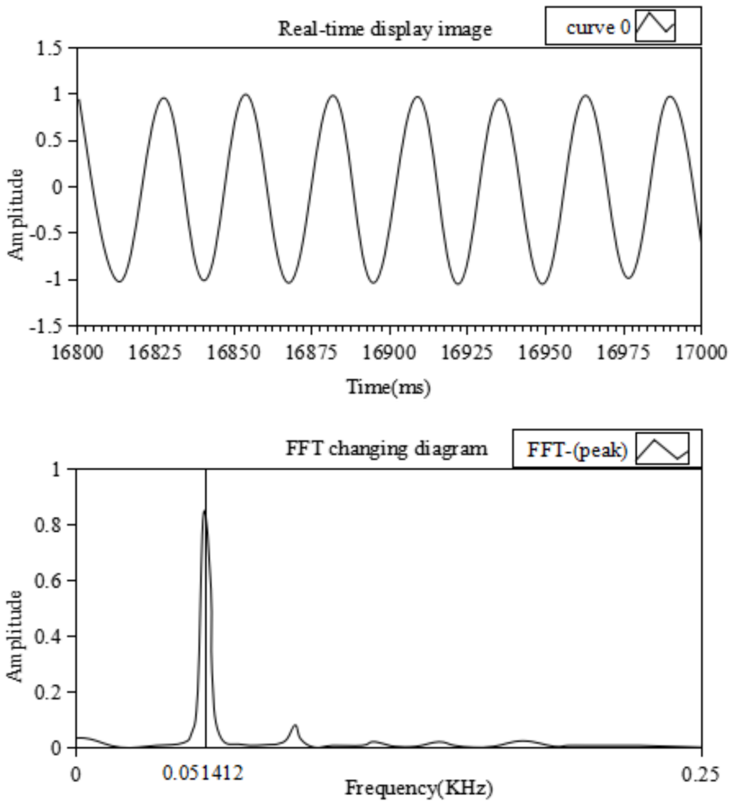

Fig. 12. 50 Hz vibration signal detection result: up–time domain diagram, bottom–spectrogram

As the system has a test to vibrostand's sinusoidal vibration signal, its oscillogram is basically in accordance with the sinusoidal waveform in the time domain diagram. In the spectrogram, it is clearly seen that frequency corresponded by the highest peak point of frequency spectrum curve is the vibration signal frequency. To sum up the testing results, feasibility and reliability of wireless vibration detection system are verified.

From Table 1, with the vibrostand's vibration frequency increased, relative error

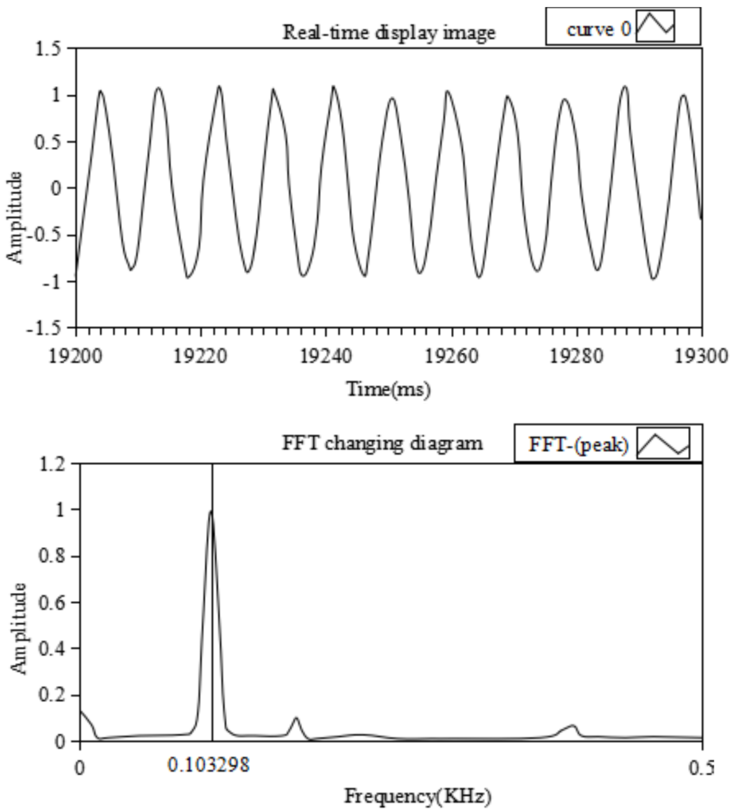

Fig. 13. 100 Hz vibration signal detection result: up–time domain diagram, bottom–spectrogram

of vibration frequency gained from the wireless vibration detection system is also increased accordingly. According to sampling theorem, with vibration signal frequency increased, the measured relative error is getting larger in sampling frequency's condition. From Table 1, if vibration signal frequency is below 100 Hz, the relative error of the measured vibration frequency is no more than 5 %.

Table 1. Relative error of wireless vibration system's measurement result

Vibration signal frequency (Hz)	Measured value (Hz)	Relative error (%)
10	10.158	1.580
50	51.412	2.824
100	103.298	3.298

And the error should include the highest peak position error chosen from frequency spectrum curve. Because the highest peak positions are chosen differently, the corresponding frequency values are various. If the system's sampling frequency is improved, the relative error can be reduced far less than 1 %. However, the present systematic function has basically met the functional demand, especially in human health.

7. Conclusion

Main content of the research is as follows: In the hardware design, STC single chip is taken as microcontroller center of signal acquisition and ADC0804 chip is selected as ADC. Vibration signal is first picked up by sensor, and then enlarged and smoothing circuit to transmit to A/D converter. At last, the acquisition of vibration signal is completed by SCM controlling the A/D converter. LabVIEW development platform is selected to design upper computer's UI whose design is mainly concentrated on three functions to program: real-time display, vibration data storage and analysis. In order to research the feasibility and reliability of the designed wireless vibration signal detection system, a vibration test platform is built to make a wireless vibration test to the several frequency sinusoidal vibrations. From the testing result, this system has a good performance whether in reliability or instability, which provides a technical reference for wireless vibration detection.

References

[1] E. T. Esfahani, S. Wang, V. Sundararajan: *Multisensor wireless system for eccentricity and bearing fault detection in induction motors.* IEEE/ASME Transactions on Mechatronics *19* (2014), No. 3, 818–826.

[2] G. Cazzulani, S. Cinquemani, L. Comolli, A. Gardella, F. Resta: *Vibration control of smart structures using an array of Fiber Bragg Grating sensors.* Mechatronics *24* (2014), No. 4, 345–353.

[3] W. Wang, O. A. Jianu: *A smart sensing unit for vibration measurement and monitoring.* IEEE/ASME Transactions on Mechatronics Acoustics *15* (2010), No. 1, 70–78.

[4] S. Korkua, H. Jain, W. J. Lee, C. Kwan: *Wireless health monitoring system for vibration detection of induction motors.* IEEE Industrial and Commercial Power Systems Technical Conference (I&CPS), 9–13 May 2010, Tallahassee, FL, USA, IEEE Conference Publications (2010), 1–6.

[5] Y. Q. Ni, B. Li, K. H. Lam, K. H. Law: *In-construction vibration monitoring of a super-tall structure using a long-range wireless sensing system.* Smart Structures and Systems *7* (2011), No. 2, 83–102.

[6] M. Hong: *A real-time pulse wave detection device basing on signal envelope.* IEEE International Conference on BioMedical Engineering and Informatics, 16–18 October 2012, Chongqing, China, IEEE Conference Publications (2012), 812–816.

[7] G. Q. Xi, F. M. Tian, J. H. Wu, Y. J. Wang: *Design of tissue-engineered myocardial contractile force detection system based on VB and MCU.* International Conference on Electronics, Communications and Control (ICECC), 16–18 October 2012, Zhoushan, Zhejiang, China, Publishing IEEE Computer Society (2012), 1952–1955.

[8] J. Lemke: *Remote vibration monitoring system using wireless internet data transfer.* SPIE–The International Society for Optical Engineering, Proceedings of the SPIE *3995* (2000), 436–445, Code 2000SPIE.3995..436L.

[9] H. S. Yoon, S. Y. LeeY, J. T. Kim, J. H. Yi: *Field implementation of wireless vibration sensing system for monitoring of harbor caisson breakwaters.* International Journal of Distributed Sensor Networks *8* (2012), No. 12, paper 597546.

[10] A. S. Weddell, G. V. Merrett, S. Barrow, B. M. Al-Hashimi: *Vibration-powered sensing system for engine condition monitoring.* IET Conference on Wireless Sensor Systems (WSS), 18–19 June 2012, London, UK, IET Conference Publications (2012), 1–5.

[11] K. Loh, J. Lynch, Y. Wang, K. H. Law, M. Fraser, A. Elgamal: *Validation of a wireless traffic vibration monitoring system for the Voigt Bridge.* World Forum on Smart Materials and Smart Structures Technology (SMSST), 22–27 May 2007, China, CRC Press (2008), Chapter No. 26.

[12] Y. Lei, W. A. Shen, Y. Song, J. P. Lynch: *Application of wireless monitoring system for the ambient vibration study of the Wuyuan steel arch bridge.* World Forum on Smart Materials and Smart Structures Technology (SMSST), 22–27 May 2007, China, CRC Press (2008), Chapter No. 54.

[13] K. D. Nguyen, J. T. Kim, Y. H. Park: *Long-term vibration monitoring of cable-stayed bridge using wireless sensor network.* International Journal of Distributed Sensor Networks *9* (2013), No. 11, paper 804516.

[14] G. Feltrin, K. E. Jalsan, K. Flouri: *Vibration monitoring of a footbridge with a wireless sensor network.* Journal of Vibration and Control *19* (2013), No. 15, 2285–2300.

[15] A. S. Ramirez, R. Loendersloot, J. M. J. Becker, T. Tinga: *Design framework for vibration monitoring systems for helicopter rotor blade monitoring using wireless sensor networks.* International Workshop on Structural Health Monitoring - Stanford University, CA, USA, 10–120 September 2013, DEStech Publications *114* (2013), Nos. 3–4, 1039–1046.

Received May 7, 2017