Multi-channel wireless network based vibrational sensing technology

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ABSTRACT: This paper proposed a wireless sensing technology which uses the public mobile communication network to transmit the low frequency structural vibration measurement. Each sensor is turned on the Internet through a general packet radio service (GPRS) module. Since some true-time operations can be carried on through the Internet, we can remotely set the operational parameters, such as the sampling frequency, the enlargement factor and so on, for vibrational data collection and transmission. So the multi-channel vibration test and data collection can be continuously and remotely conducted in a wireless way at the place which is covered by the mobile communication network. The principles and the technical characteristic of this technique as well as a preliminary application in the bridge vibration test are presented in this article. The results show the proposed technique is of great potential to be adopted for structural health monitoring.

1. INTRODUCTION

Along with the fast development of the researches and implementations of structural health monitoring (SHM) projects, the remote data collection and transmission techniques are in great demand. The wireless data collection and transmission techniques meet this requirement and attract more and more research interests. This article proposed a wireless sensing technology which uses the public mobile communication network to transmit the low frequency structural vibration measurement. Each sensor is turned on the Internet through a general packet radio service (GPRS) module. Since some true-time operations can be carried on through the Internet, we can remotely set the operational parameters, such as the sampling frequency, the enlargement factor and so on, for vibrational data collection and transmission. So the multi-channel vibration test and data collection can be continuously and remotely conducted in a wireless way at the place which is covered by the mobile communication network. The principles and the technical characteristics of this technique as well as a preliminary application in the bridge vibration test are presented in this article.

2. THE CONSTITUTION OF THE SENSOR

The GPRS (General Packet Radio Service) is one kind of the GSM mobile communication technology. Its maximum data transmission speed is 171.2Kbps; the present practical speed is about 13-40 Kbps. The special advantage of the GPRS is it can access the net wirelessly at anytime and anywhere and it only takes a few seconds to be registered on the Internet. Since its charge only depends on the current capacity, it can realize "on-line forever". It provides the standard RS-232 connection to the exterior. The wireless network vibration sensor connects the GPRS data transmission module using this connection, and thus realizes the wireless vibration measurement. The wireless network vibration sensor is mainly composed of the vibration sensor, the controllable filter amplifier, the GPRS data transmission module adapter and the GPRS data transmission module (as Figure 1 shows).

In this figure，the hardware in the left four squares constitutes a wireless network vibration sensor. The sensor accesses to the net wirelessly through its GPRS data transmission module. One the left, there are a host control computer and its terminal access equipments. The terminal equipment can access the net by using the wired way of the telephone digit dialing, or ADSL (also may use wireless way to access the net). Thus the host control computer is able to operate on each wireless network vibration sensor in a real-time way. The control computer receives the vibration measurement data from each sensor, and then stores these vibration data in its memory.

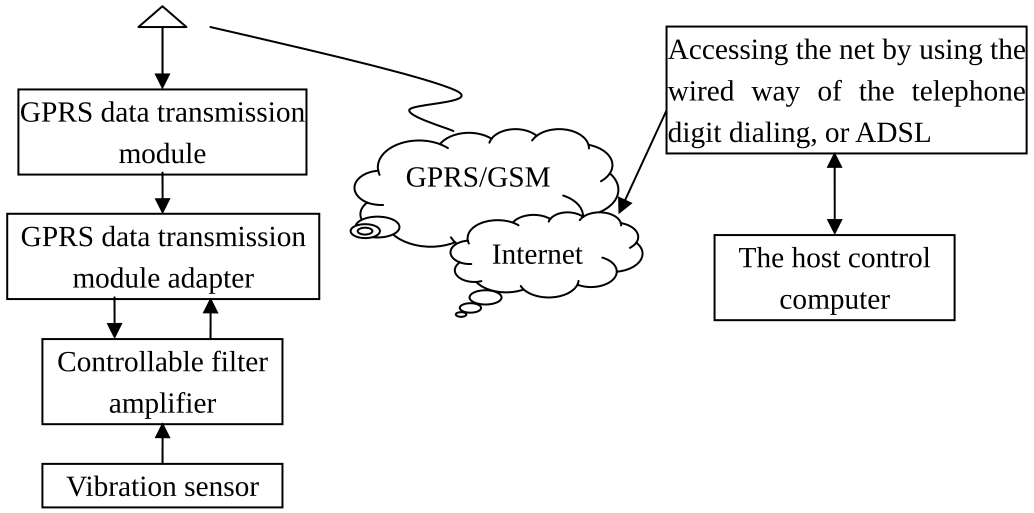

Figure 1 Wireless network vibration sensor constitution block diagram

In Figure 1, the vibration sensor could be the piezoelectricity accelerometer as well as other types of accelerometers. After the enlargement by the controllable filter amplifier, the measured vibration signal enters the GPRS data transmission module adapter. This adapter will be connected to the corresponding connection RS-232 after the suitable matches of the vibration signal. The highest corresponding speed of the RS-232 connection will be 115.2Kbps. It is connected to the net through the GPRS data transmission module. The operational parameters of the controllable filter amplifier, the AD sampling frequency and the vibration measurement data are all controlled and transmitted by the GPRS data transmission module adapter and the GPRS data transmission module.

In the wireless network vibration sensor, the key component is the GPRS data transmission module adapter. Figure 2 is a schematic drawing of its internal constitution.

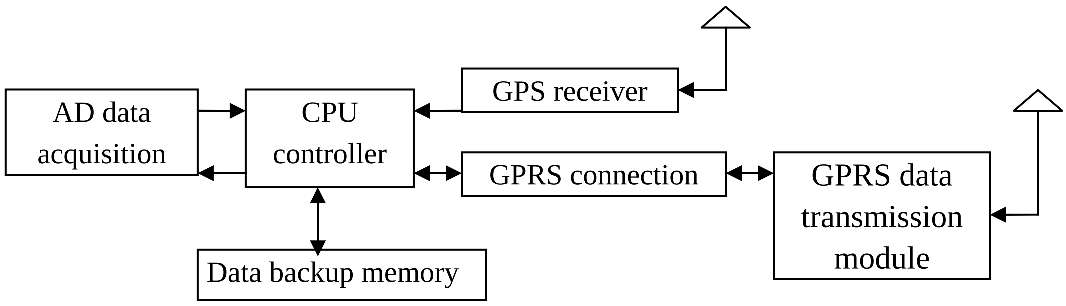

Figure 2 The schematic drawing of the GPRS data transmission module adapter

The GPRS data transmission module adapter is composed of a AD data acquisition device, the CPU controller, the GPS receiver, the data backup memory and the GPRS connection electric circuit. The CPU controller uses 8 monolithic of 51 series to carry on the overall system suitably to match the control. The GPS receiver is used for synchronized data gathering. The data backup memory can store the vibration measurement data temporarily which is used for future replacement of the data. The GPRS connection connects the GPRS data transmission module, so as to complete the transmission the vibration measurement data.

For the bridge vibration measurement, the sampling frequency of the developed wireless network vibration sensor could be 5.12Hz, 12.8Hz, 25.6Hz or 51.2Hz. The precision of the AD modulus switch is 12bit; the switching time is 8.5us. In the controllable filter amplifier, the frequency of the low pass filter could be 1, 2, 3, 5, 10 or 20Hz.

Its stop-band attenuation is -24dB/oct. The enlargement factor of the amplifier is 1-5000 times according to 1, 2, 5, 10 percentages which is divided into 11 grades. The biggest input voltage is ±5V. The host control computer can carry on the real-time wireless operation to the sampling frequencies of these wireless networks vibration sensors, the filter frequency and the enlargement factor just like the traditional wired vibration measurement system. It enables them to achieve the best vibration measurement condition. For power supply, both the alternating and the direct electricity can be used.

3. TECHNICAL CHARACTERISTIC OF WIRE -LESS NETWORK VIBRATIONAL SENSOR

The transmission of the vibration data between the public mobile communications network and Internet will induce the indefinite time delay. After the host control computer terminal send out the start data acquisition instruction to each wireless network vibration sensor (secondary machine), this instruction have a indefinite time to arrive each wireless network vibration sensor as a result of the network transmission time determinism. The different arriving time may be accumulated to several hundred milliseconds, therefore it is unable to realize precise synchrony data gathering. This situation can not permit in certain oscillator measurements, and is one of the obvious differences between the wired measurement and the wireless measurement.

In addition, in consideration of the data transmission timeliness, the general GPRS data transmission module uses the UDP communication agreement. The data wraps of this kind of UDP agreement will induce data loss when they are transmitted through these two kinds of networks. The loss degree is depended on the communication condition of these two networks. The loss rate we tested initially is about 1 - 10%. Therefore this kind of GPRS wireless communication network is not suit for the continual data transmission. However, the vibration measurement data must be continual. This is also one of particular aspects of wireless network vibration measurement.

4. SYNCHRONIZED DATA ACQUISITION OF WIRELESS NETWORK VIBRATION SENSOR

Because of the indetermination of the time delay, it is very difficult to get the precise synchrony data collection between the wireless network vibration sensors. Therefore, if the strict request on synchronized data collection is needed, we can only realize this based on the support from the standard clock in global positioning system (GPS). Figure 3 shows the working theory.

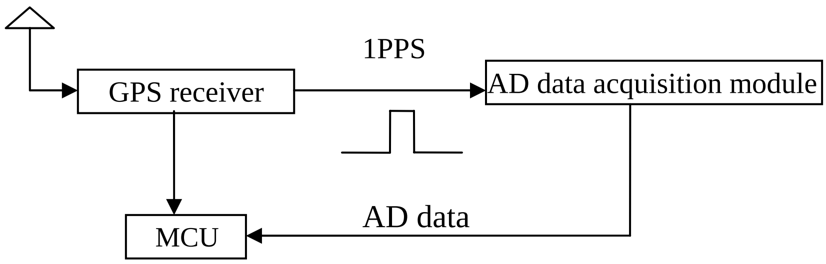

Figure 3 the principle block diagram of using GPS to realize synchrony data gathering

The receiver of the GPS is able to export a second pulse per second after it was fitted, namely 1 PPS second pulse. The synchronization error of the rise front between this second pulse and the world coordination time (Universal Coordinated Time, abbreviation was UCT) might amount to ±1 microsecond generally. Meanwhile, the serial interface of the GPS also can export its related time information between each two pulses. This can be used to explain the UCT time year, month, date, hour, minute. This can also tell the second that is before this 1 PPS second pulse corresponds. So it is applicable to use the standard UCT time of GPS and its rise front of the second pulse as the time benchmark to realize the synchronized data collection of many wireless networks vibration sensors.

We install a GPS receiver on each wireless network vibration sensor to receive 1 PPS second pulse and the UTC time. This receiver can then export and carry on synchronized data collection using the rise front of 1 PPS second pulse. Its process is: establishing a minute time on the control computer to start isochronous vibration data acquisition; taking the first second of the current time's latter 1 minute which is intercalated by the control computer automatically as the synchronized data collection time; transmitting it to each wireless network vibration sensor (quite one point to multi-points communications style); making them all to carry on the vibration data collection at the rise front of the second pulse of this time. In this way, we can realize the synchronized data collection of each wireless network vibration sensor. Its synchronization error is depended on the time precision of GPS's 1 PPS second pulse. It may be a microsecond.

In order to achieve this synchronized precision, we start the data acquisition directly by using 1 PPS second pulse through the hardware electric circuit. That guarantees the precise opening of synchronization A/D data collection when the rise front of 1 PPS arrives. Figure 4 shows the initial sector waveform under the input of the identical sine-wave signal (1.060Hz) synchronized data collection of 3 wireless network vibration sensors of which the sampling frequency is 51.2Hz. This is the initial waveform which is captured at the real-time. The data is in gathering continuously (the control computer access the net with digit dialing method, the speed is 50.2Kbps). It can be seen in the figure obviously their outset phase is completely consistent. The waveform of the 2nd channel among the figure shows discontinuous phenomenon (it is random). The data-loss is observed from the discontinuousness of the waveform. After the data picked completely, it will be continue by resending automatically, it was showed on the 2nd channel in figure 6, because of the software restriction, only the waveform of 2 channels can be demonstrated in figure 6 at present.

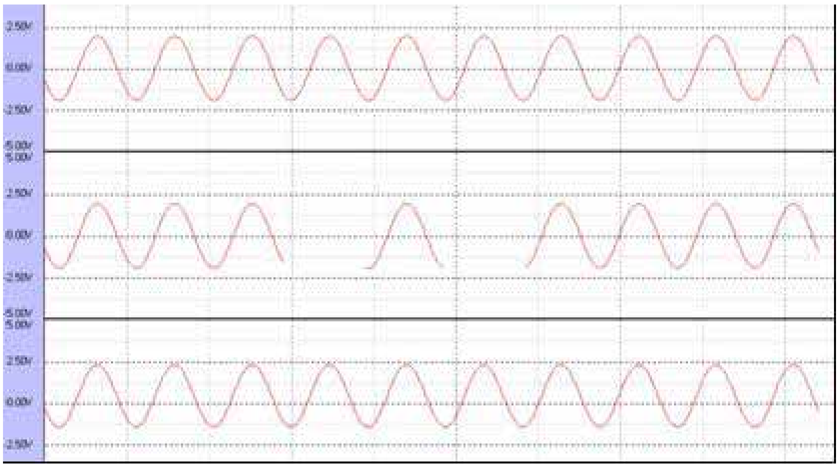

Figure 4 Initial sector of oscillogram of using the GPS norm time to realize synchrony data collection

Figure 5 is data collection wave-form of 3 wireless networks vibration sensors without the GPS to carry on synchronously. The input signal is also the identical sine wave (1.060Hz). The sampling frequency is also 51.2Hz. It can be seen in the figure that their outset phase have the difference. It also can be seen that the data has very little loss when the communication network condition is good.

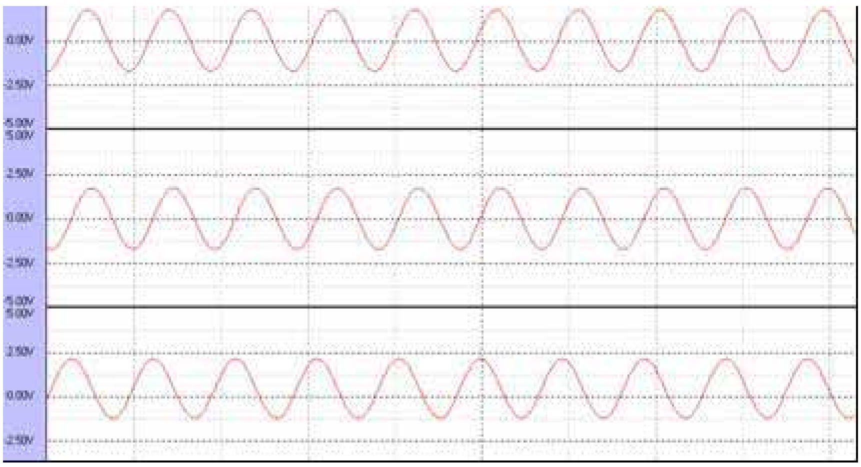

Figure 5. The collected waveform of 3 wireless networks vibration sensors without the GPS to carry on synchronously

We also carried on the test on synchronized data collection of two wireless networks vibration sensors by using the bi-pass digital oscilloscope (at present the bi-pass is the only choice). At the same time the front wave-form of the AD sampling start pulse of these two wireless networks vibration sensors were monitored. The experimental result showed its synchronization is completely consistent with the GPS 1 PPS second pulse synchronized precision. The precision may achieve ±1 to 2 uS. In this way, we can realize microsecond magnitude of a wireless oscillator measurement by using the GPS standard clock synchronized data collection. This synchronized precision has nothing to do with the wireless network vibration sensor's quantity.

In addition, after the control computer to send out the hypothesis time instruction of synchronized data collection of all wireless network vibration sensors, if one (or several) of the wireless network vibration sensors has not received this synchronized data collection instruction, the control computer will resend the instruction automatically (resend 3 time). Thereafter, all of the wireless networks vibration sensors can receive this instruction before the hypothesis synchronized data collection time. That guarantees the execution of this synchrony data gathering instruction.

5. DATA TRANSMISSION OF WIRELESS NETWORK VIBRATION SENSOR

The data transmission of the wireless vibration measurement through the present wireless network will induce the indefinite data loss. Although sometimes the loss rate is very low, sometimes the loss rate can reach 10%. Therefore we have made a vibration measurement data backup on each wireless network vibration sensor. The data backup capacity of the experiment model can reach 256KB. After a vibration data acquisition completes, the control computer will immediately inspect the received data, record the leaked data, and then send the orders to each wireless network vibration sensor to take out these leaked data which will be resend to the control computer immediately from their data backup until the oscillator measurement data is complemented completely.

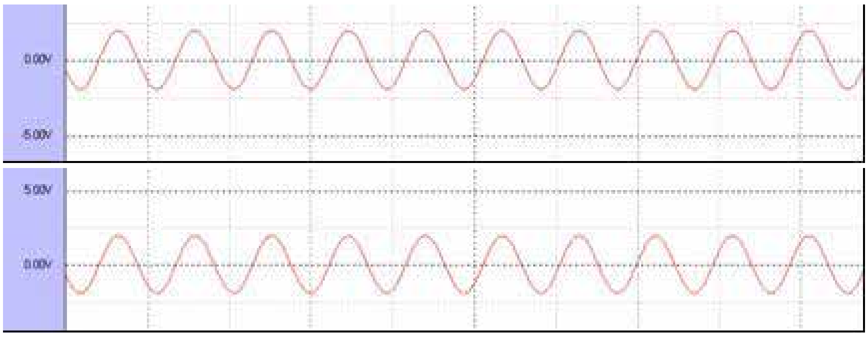

Figure 6 the waveform of the data which was resent by the control computer automatically (resending the gathered data automatically in figure 4)

The waveform of the renewed data is shown in figure 6. It is the waveform of the 1st and the 2nd channel which was renewed automatically after the data acquisitions of 3 channels in figure 4 was completed. The discontinuous waveform of the 2nd channel in the original figure 4 comes to be continual after it was resent. We also have carried on proofreading to this gathering data file data. It was discovered that the data is complete after it was resent automatically.

In addition, we also did an experiment about the time exhausted by resenting of data using 3 wireless networks vibration sensors. The control computer logs on the internet through the dialing method, the speed can reach 28.8Kbps. The control computer sends out the order to these 3 wireless networks vibration sensors to carry on synchronized data collection with a sampling frequency of 25.6Hz. The time of continuously gathering of the data is 10 minutes. The time exhausted by resending the entire received data is about 1/15 of the time of collection. It is said that the control computer has completed the resending of the collected data of these 3 sensors after 40 seconds.

6. THE WIRELESS VIBRATIONAL TESTS

In order to examine the in-situ operating performance of this wireless sensor system, an actual vibration test has been carried on a footbridge which is a steel structure. Two wireless network sensors were set respectively along the vertical and the horizontal direction at the middle of the bridge. The host control computer was placed in the laboratory which is several kilometers far from here. The communication between these two wireless network sensors and the host computer was setup through the telephone digit dialing. The sampling frequency was 25.6Hz. The filtering frequency was 10Hz. For the sensor in the vertical direction, the amplifier's enlargement factor is 10 times, and the horizontal direction the enlargement factor is 50 times. During the tests, approximately 12 minutes isochronous vibrations data acquisition is carried on. Its partial acceleration waveform is shown in Figure 8 (Ch1 is the vertical direction vibration acceleration; Ch2 is the horizontal direction vibration acceleration). When the test was carried on, the footbridge was under the excitation of crowd loads and the vehicle streams which was under the footbridge. Moreover, on the top of it the light axle train passed frequently. The vibration sources are very complex and the input vibration energy is great. The bridge floor vibration is evident. All these phenomena will induce you discomfort. Analysis of the acceleration record also indicated that the vibration effect of this footbridge is obvious.

Figure 7 Vibration test of a steel structure footbridge

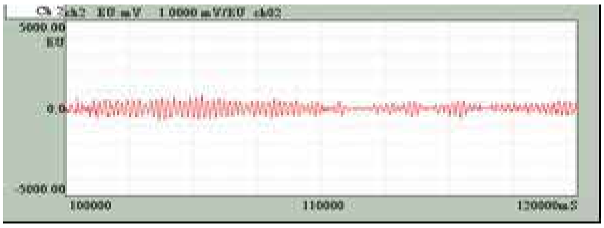

Figure 8 The vertical direction and the horizontal direction vibration acceleration waveform of a steel structure footbridge which was under the function of the light axle vehicles through under the bridge

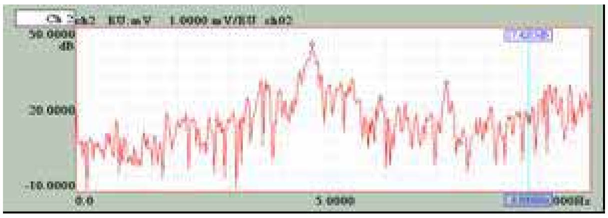

Figure 9 The vertical direction and the horizontal direction acceleration power spectrum of the steel structure footbridge which was under the function of the light axle vehicles through under the bridge

7. CONCLUSION

In this paper, a wireless network vibration sensor is developed. It realizes the wireless vibration measurement by using the GPRS data transmission module to connect Internet through the GSM public wireless communication network. The GPS receiver was used to realize synchronized data collection at microsecond magnitude of ±1 ~2us. At the same time we also have solved the data loss question in the wireless network transmission process. So the multi-channel vibration test and data collection can be continuously and remotely conducted in a wireless way at the place which is covered by the mobile communication network.

The deficiency of these sensors is that the cost of the hardware is high at present and the use of GPS is not convenient: its antenna must be put up in the open region. Besides that, other deficiencies include the lost of power source is significant, the fees must be paid because of the wireless transmission data, and the covered region of GSM network signal is also insufficiently broad at the present.

Because of the use of public wireless network to realize the wireless vibration measurement, we only need to concentrate the energy in the hardware of wireless network vibration sensor and the usage of hardware related with the network. Therefore the expense of setting up the wireless vibration measurement network can be omitted. Along with the increase of wireless vibration sensor's quantity in the wireless vibration measurement system, the wireless vibration measurement network will be more complex. Its cost of development and the maintenance will also be high increasingly. Therefore, the wireless network vibration sensors using the public wireless communications network have the good application prospect.

The performance of wireless network vibration sensor has a direct correlation to the performance of the GSM wireless network. The GSM wireless network will be promoted unceasingly, namely from 2.5G to 3G or 4G. This means that the band width for data transmission will be extended and the transmission will be more stable. Therefore, the performance of wireless vibration measurement technology will be promoted automatically and freely.

The band width of the wireless network vibration sensor is decided by the band width of the GPRS data transmission module. The present sampling frequency may achieve 256Hz in theory. But the control computer can access the net using the ADSL. By now its band width might only achieve 1-2Mbps. This will be one of the questions to be solved in the next step.

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In this article the tentative plan of using the public wireless correspondence network to realize the low frequency vibration measurement is proposed by Professor Shi Jiajun of bridge laboratory of Tongji University. Some technical plans are also discussed with him. We also obtain the support in many aspects from the bridge health monitoring laboratory of Tongji University and the bridge laboratory of Tongji University. In addition, we also obtain the support from the Shanghai science committee which established the research project.

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