Integration and tests of wireless strain sensor applied to structural local monitoring

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ABSTRACT: As there exist some problems for strain collection and transmission system, a kind of wireless sensor and system applied to structural strain monitoring is proposed according to principle of resistance-strain gauge; The modules and functions of the system core, wireless strain sensor, are introduced importantly; The design of the typical circuit is discussed in detail, and the test results of the designed system are given finally. The research indicates that the wireless collection and transmission system designed has such many characteristics as collecting in precision, transmitting reliably, low cost, used simply and handily, and that it is applied compatibly to civil engineering monitoring.

1 INTRODUCTION

According to Housner, et al.(1997), structural health monitoring(SHM) is defined as "the use of in-situ, non- destructive sensing and analysis of structural characteristics, including the structural response, for detecting changes that may indicate damage or degradation". Recently, SHM has emerged as an important research area in civil engineering structures (Ou & Guan 1999, Farrar et al. 2001). Usually, SHM is divided into global and local monitoring, the global monitoring technique is mature, but it can not provide local orientation information; Meanwhile, it is effective to estimate the status of structures for the local monitoring technique. Therefore, local monitoring is popular in SHM.

Different sensors are used for gathering diagnostic information, this also ensures making SHM and diagnosis. As a kind of effective sensing unit, the resistance strain gauge is applied for local monitoring this many a day. For the existent strain collection and transmission systems, the strain collection gauge is big, the circuit performance and collection precision is affected by wire length and the installation and maintenance costs can be very high, all the above slow down local sensing units' application.

In this paper, a kind of wireless strain sensor and system for local monitoring is integrated using commercially available components, from the integration, miniaturization, high-reliability and low cost aspect.

2 RESISTANCE STRAIN GAUGE AND ITS COLLECTION SYSTEM

Adhibited on the surface or embedded in a structure, the resistance strain gauges are steady and durable, they can form different arrays; they do not almost disturb the performance of monitoring material as the volume of a resistance strain gauge is small; the resistance strain gauge has some merits: produced easily, low cost, high-temperature and shock resistance.

2.1 *Operating principle of Resistance strain gauge*

Mechanical transmogrification produces while resistance strain gauge receives outside force, and then the resistance changes with the change of strain, this is resistance-strain effect. The strain measurement is finished by this principle (Hou Guozhang 2000).

For a piece of wire, if "l" is the length, "S"(S= πr^2) is section area, "ρ" is resistance coefficient, its resistance "R" is defined without outside force：

$$R = \rho \frac{l}{s} \tag{1}$$

After wire is pulled, its length, section area and rate of resistance change, these changes can be presented in formula 2 by the way of whole differential coefficient：

$$\frac{dR}{R} = \frac{dl}{l} - 2\frac{dr}{r} + \frac{d\rho}{\rho} \tag{2}$$

Where

dR/R -- Relative variables of resistance

dl/l -- Lengthways relative variables (axial strain)

dr/r -- Relative variables of radius (radial strain)

$d\rho/\rho$ --Relative variables of resistance coefficient

According to the material mechanics, the relation between axial strain and radial one is given as follows,

$$\frac{dl}{l} = \varepsilon , \quad \frac{dr}{r} = -\mu\varepsilon \tag{3}$$

The formula 2 is transformed,

$$\frac{dR}{R} = (1+2\mu)\varepsilon + \frac{d\rho}{\rho} \tag{4}$$

For metallic material, the change of its $d\rho/\rho$ is tiny and may be skipped, u is constant, so the sensitivity coefficient of strain metallic material is defined:

$$K_0 = \left(\frac{dR}{R}\right)\Big/\varepsilon = 1+2\mu \tag{5}$$

From the formula 5, we can see that the resistance rate is direct ratio with strain for strain metallic material, this means that strain is the accordance with the resistance change measured directly.

2.2 *The traditional collection and transmission method of strain*

The traditional collection and transmission of strain signal is showed in figure 1: the resistance of strain gauge change with the role of strain. The change is transmitted to strain collection and transmission device(**C & T device**) by wire and then transformed into weak voltage signal. After being amplified and filtered, the voltage signal is transmitted to computer for next disposal. In this system, the strain collection and transmission device is usually not fit for being put the monitoring position because of its big volume, the distance between the strain collection and transmission device and the resistance strain gauge is about tens of meters, and the change of strain gauge's resistance is usually small, this requests that the resistance of wire does almost not change to get a more précised strain-measured value. Consequently, the wire with high-performance is needed in this system, this will increase the installation cost. And that the weak signal is transmitted by long wire will reduce the reliability of the entire system. In other words, even if the gauge could be put closely the monitoring position, the computer in the monitoring center would be far from the gauge in this system, this also make signal transmit inconveniently.

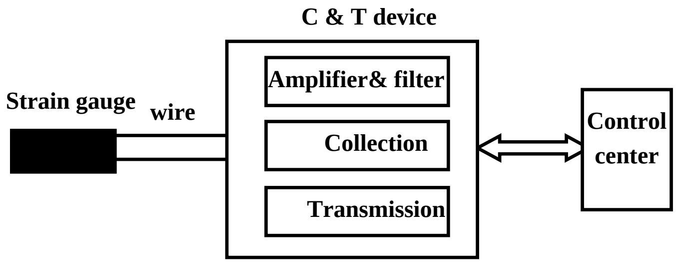

Figure 1 Strain signal collection and transmission system

3 WIRELESS COLLECTION AND TRANSMISSION SYSTEM OF STRAIN

Wireless collection and transmission system of strain signal is designed for structural local monitoring. As showed in figure 2, the wireless collection device can be put close enough to the strain gauge(usually in about 10 cm), and they make up the wireless strain sensor together. This so, the system can get over the defection of traditional collection method that too long wire interferes collecting right. Meanwhile, strain signal is amplified and filtered by the wireless strain sensor, and the signal is extracted by the embedded microprocessor and transmitted reliably in wireless way. In conclusion, wireless strain collection system consists of wireless strain sensor and the computer that receive the signal.

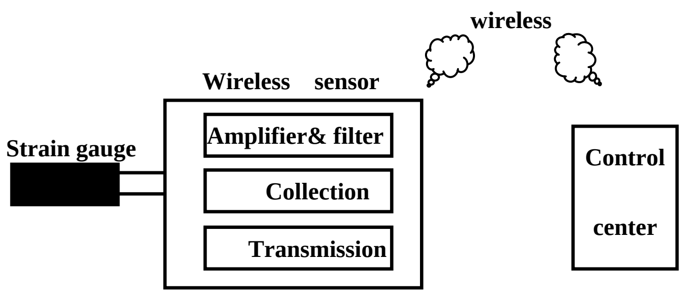

Figure 2 Wireless collection and transmission system of strain signal

4 HARDWARE INTEGRATION

4.1 *General description of wireless strain sensor*

Wireless strain sensor is integrated with existent electric components based on MEMS and embedding technique. According to the idea of developping wireless acceleration sensor(Yu & Ou 2004), wireless strain sensor is developped by moduliaztion(Ou & Li 2003, Spencer 2003)， consisiting of strain disposal unit, microprocessor, wireless transiever and energy unit,as is showed in figure 3.

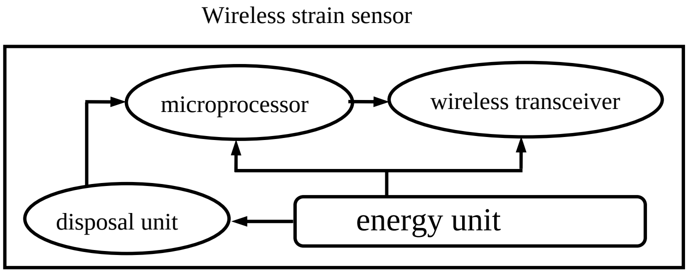

Figure 3 Modules of a wireless strain sensor

Holding the terminals connected with strain gauge, strain disposal unit circuit hasthe such functions as resistance-voltage signal transformation, amplifying and filtering signal. The microprocessor can collect and pre-dispose the signal output by strain disposal unit circuit, otherwise, it also can transmit strain signal extracted to wireless transceiver. Wireless transceiver module is in charge of the entire device's communication with the computer. Energy unit is lithium battery providing the energy for the entire system. The above modules are designed independently and then integrated into a wireless strain sensor.

4.2 *Typical circuit design*

4.2.1 *Strain disposal circuit*

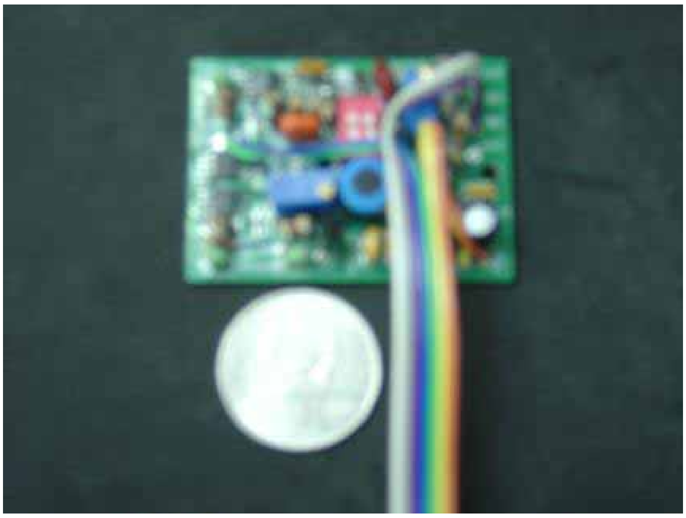

Figure 4 Strain disposal board

Strain sensing board shown in figure 4 is designed for monitoring the strain by the mode of voltage signal transmitted from resistance change. There are mainly the circuits of amplification and filtering, the schematic diagram is presented in figure 5.

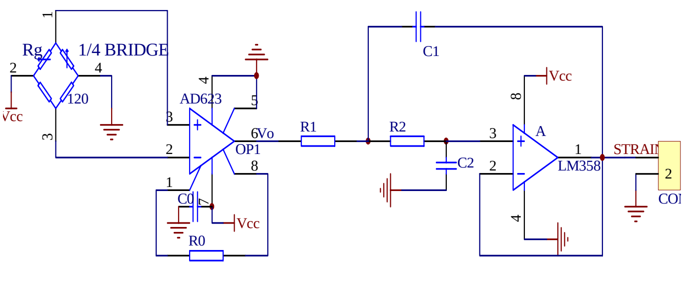

Figure 5 Schematic diagram of former disposal circuit

As micro-changing signals are accomodated in amplification, we select instrument amplifier, AD623, which has the characteristics of high input resistance, low maladjustment voltage and driftting temperarture coefficient, statable amplifing multiple, low output resitance. Besides the above characteristics, AD623 selected in this design has the following specialty: it has high performance in a single-end power source, the output voltage could swing in rail to rail output, Its gain could be adjusted from 1 to 1000 by the use of gain resistance, It needs a few periphery parts of an apparatus, It is low power and little encapsulation. By the equation 6, the gain resistance is selected according to magnification multiple, the gain G is 500 and then R_0 is 200Ω.

$$R_0 = \frac{100k\Omega}{(G-1)} \tag{6}$$

The two steps of Butterworth circuit, making up of R_1, R_2, C_1, C_2 and magnifier in figuer 5, is used for a filtering one. The signals of civil engineering structures belong to low frequency ones, so the bandwidth with 20Hz could meet the requirment. And LM358 with the characteristics of little encapsulation, single-end power souce and low power, is selected as a magnifier. According to the equationg 4, the components are decided: R_1=100$k\Omega$, R_2=91$k\Omega$, C_1=0.1uf ,C_2=0.047uf, and the acutal cut-off frequency(i.e Q=0.707) is 25Hz, this means that the Vo in figure 5 is kept in its amplitude value and is filtered above the bandwidth of 25Hz .

$$\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}} = 2\pi f \qquad Q = \frac{\sqrt{R_1R_2C_1C_2}}{C_2(R_1+R_2)} \tag{7}$$

In the above disposal circuit, the change of the strain gauge could be output by a standard voltage signals.

4.2.2 *Microprocessor circuit*

The processing unit on the sensing and processing board could gather, pre-process the analog and digital output from the detection unit. And it could also exchange data with the wireless transceiver.

The processing unit used in this design is Atmega8 chip, which integrates a large storage memory and interface circuits. As a microprocessor with low cost, the chip adopts a small pin package. It's main features are as follows: 8 bit high performance, low cost AVR micro-controller with advanced RISC simplified instruction aggregation structure, a number of powerful external interface circuits, and five sleep modes including idle, ADC noise reduction, power-save, power-down, and standby.

In otherwise, the microprocessor's A/D interface is used for gathering the voltage signal transformed from strain.

4.2.3 *Wireless transceiver circuit*

Wireless communication board is used to transmit data measured by the sensors to the base station. In this design, the wireless communication board is developed on the basis of CC1000, a true single-chip RF transceiver with a ultra high frequency range and low power requirement. The CC1000 circuit is mainly used for the industrial, scientific and medical (ISM) gauges. It is a short-range device (SRD) with frequency bands at 315, 433, 868 and 915 MHz. But it can be programmed for operation in the 300-1000 MHz range. The FSK data transmission rate of CC1000 could reach 76.8 kBaud. These characteristics of CC1000 meet data transmission requirement in the SHM for civil engineering structures. The diagram of wireless communication board is presented in figure 6.

Figure 6 Wireless communication board

5 TEST RESULTS

The strain experiment of wireless sensor was finished using such the installation shown in figure 7. The resistance-strain gauge is affixed on a simply-supported beam, it could change regularly while the simply-supported beam is loaded in rule, and the change could be collected, disposed and transmitted wirelessly. In this test, the exiting static strain collection instrument is also used for recording the change of the resistance-strain gauge in order to demarcate the designed wireless strain sensor. The strain changes of static strain collection instrument and wireless sensor are shows in figure 8: The load/strain change for wireless sensor is well-regulated, and the change has very small difference from the one of static strain collection instrument.

Figure 7 A picture of the strain testing device

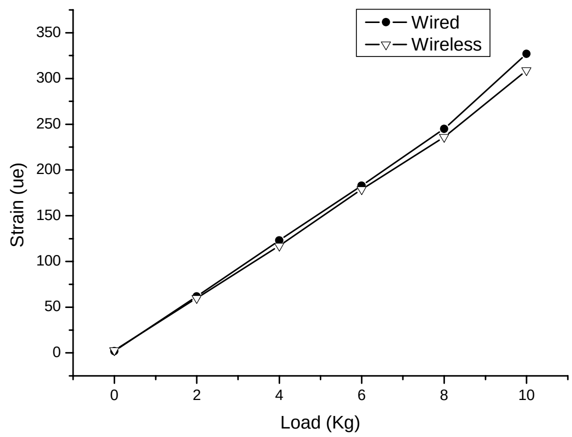

Figure 8 Load/strain change for wireless sensor and static strain collection instrument

6 CONCLUSIONS

Wireless strain sensor and system is designed and can amplify, filter, collect, pre-dispose, transmit wirelessly strain signal. The following conclusions are drawn,

（1） the load/strain change for wireless sensor is well-regulated

（2） Low cost. Compared with the traditional strain collection system, the designed system needs almost not wire and thus save installation and maintenance cost.

（3） Installed easily. The designed wireless strain system is small in volume, used simply and handily without wire.

（4） High reliability. The designed system is developed using advanced, low cost electric components, the circuit is reliable.

In general, the designed system applied to structural local monitoring can overcome the disadvantages brought by the traditional collection methods, and it is significant and compatible for engineering application.

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