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Application of Wireless Sensors for Structural Health Monitoring And Control

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ABSTRACT

Wireless sensors have been proposed for use in structural health monitoring systems because they offer low-installation costs and automated data processing functionality. To validate the performance of the proposed WiMMS (wireless modular monitoring system) on the vibration measurement of large-scale civil structures, a three-story half-scale steel structure is instrumented with a wireless monitoring system assembled from a network of six wireless sensors and tested it on a shaking table to ensure the reliability of the data communication. Field application of WiMMS to ambient vibration survey of Gi-Lu cable-stayed bridge is investigated. Finally, the preliminary study on structural control using MR-damper through WiMMS is also presented.

INTRODUCTION

The practice of using extensive cabling and high cost labor as is typical of the traditional monitoring systems will be changed to a system of inexpensive wireless embedded systems, maintained and operated with ease. Strong interest in applying wireless sensing technologies within structural health monitoring systems has grown in recent years. The advantages of wireless sensors are: they emerging as a viable monitoring system tool and provide rich amounts of mobile computing power. The use of wireless communication for SHM data acquisition was illustrated by Straser and Kiremidjian [1]. Recently, Lynch *et al.* extended the work by embedding damage identification algorithm into wireless sensing unit [2, 3]. With the rapid advancement of sensing, microprocessor, wireless technologies, it is possible to assess the benefits from the application of such technologies in the structural engineering field. The purpose of this paper is to use the developed wireless modular monitoring system (WiMMS)[4] for civil infrastructural health monitor. Both shaking table test and field experiment are conducted to enhance the reliability and applicability of the system. Seismic response control of building using WiMMS is also conducted in this study for the first time.

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WiMMS HARDWARE PROFILE

The wireless sensing unit includes three subsystems: the sensing interface, the computation core, and the wireless communication system. The sensing interface is responsible for converting the analog sensor signals into digital forms. The digital data is then transferred to the computational core by the Serial Peripheral Interface. External memory is associated with the computational core for local data storage or analysis. The hardware profile of wireless modular monitoring system is shown in Fig.1. Picture of the wirelss sensing unit is also shown in this figure. The Maxstream 9XCite wireless modem is used for the wireless communication subsystem. Its outdoor communication range is up to 300m, which is reduced to about 100m when it is used indoors. The hardware design was focused on improving the unit's performance of high-precision real-time data acquisition. The functional diagram of the unit is shown in Fig.2.

Data acquisition subsystem
- **4-channels @ 16-bit A/D conversion**

Computational core
- **8-bit ATMega128 microcontroller**
- **128 kB SRAM (data storage)**
- **128 kB flash ROM (program storage)**

Wireless communication channel
- **Maxstream 9XCite radio**
- **Highly reliable spread spectrum radio**

Completed Unit
- **Form factor:** ***10 cm x 6 cm x 2 cm***
- **Power consumption:** ***80 mA at 7.5V***

Fig. 1: Hardware profile of wireless modular monitoring system (WiMMS)

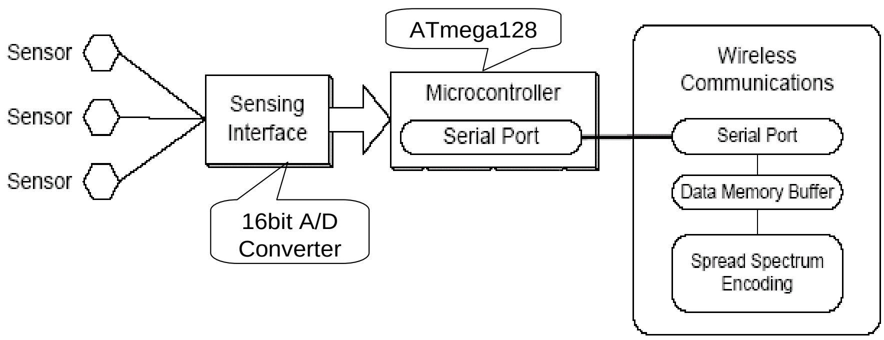


Fig. 2: Hardware functional diagram of the wireless sensing unit.

APPLICATION TO STRUCTURAL VIBRATION MONITORNG

To validate performance of the entire wireless sensing unit, validation tests using shaking table on a 3-story half-scale laboratory structure are devises (floor area: 3m×2m and story height: 3m). A total weight of the test structure is 19 tons. The Crossbow CXL02 MEMS Accelerometers (±1.0g) were installed on each floor. Both El Centro and Chi-Chi earthquake records were used as input motion to the structure. Both traditional cable-based and the wireless sensing unit systems were used to collect the response of the test structure. Fig. 3 shows the comparison on the recorded acceleration of 3rd floor from both wired and wireless sensing systems. Good agreement was observed.

Field experiment using the sensing unit was also conducted. Ambient vibration survey of a cable-stayed bridge using wireless sensing unit was also conducted. Since the sensing unit was designed for any analog signal between 0 and 5 Volt so as to be accepted by the A/D converter, than for any sensor output signal (accelerometer or velocity sensor) must meet this input voltage constraint of WiMMS. The output voltage of velocity sensors for ambient vibration survey is ±10 Volt which can not meet the input requirement of wireless sensing unit (0~5V). A signal converter must be designed. Fig.4 shows the circuit print of the designed converter and the voltage converter in operation. Fig. 5 shows the comparison of the recorded velocity signal from both wired and wireless sensor of the ambient vibration of Gi-Lu cable stayed bridge (velocity response of stayed cable).

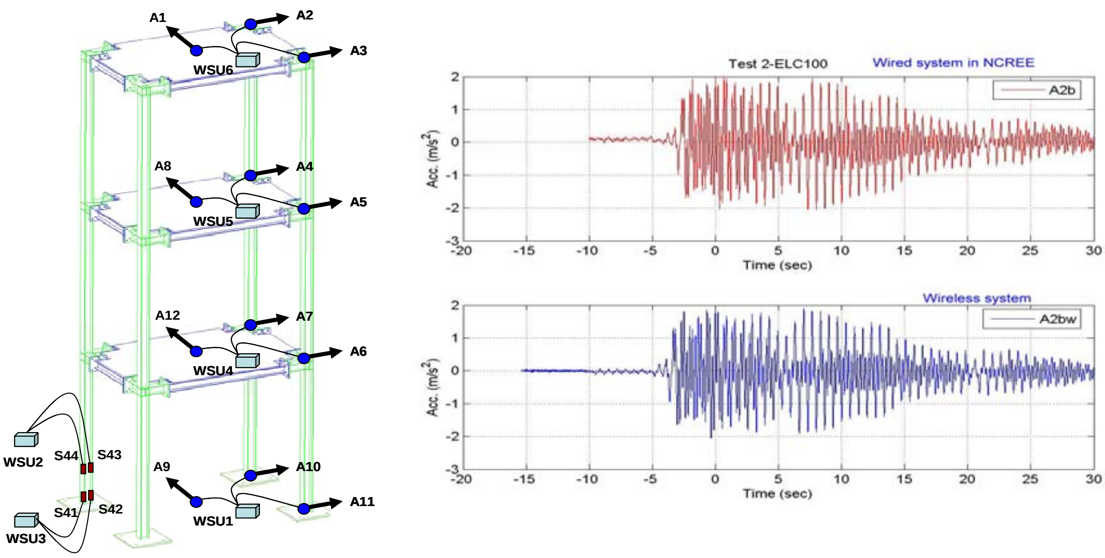


Fig.3: (a) A 3-story steel frame instrumented with wireless sensors for shaking table test, (b) Comparison on the recorded 3rd floor acceleration from wired and wireless system.

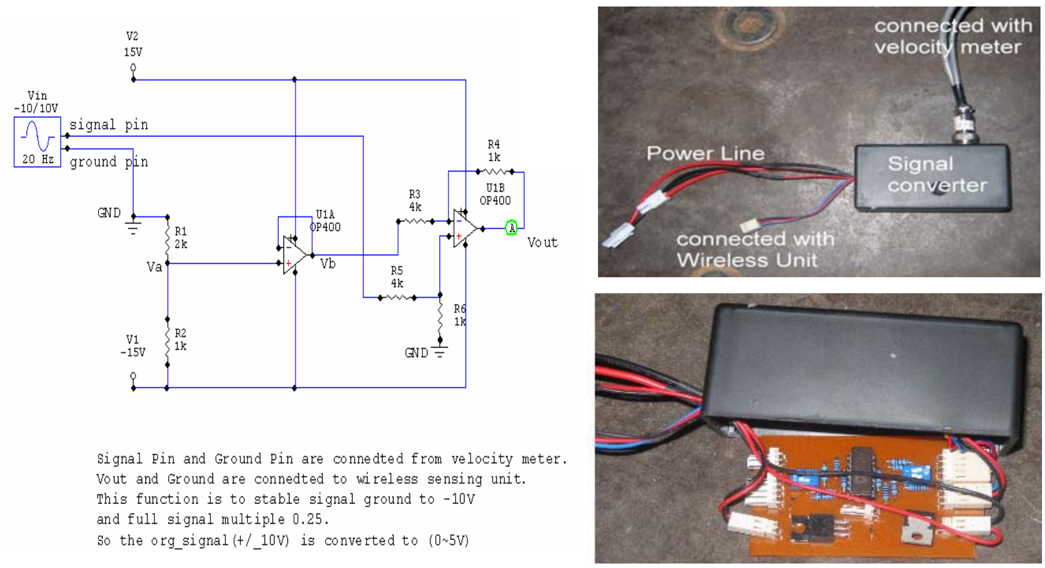
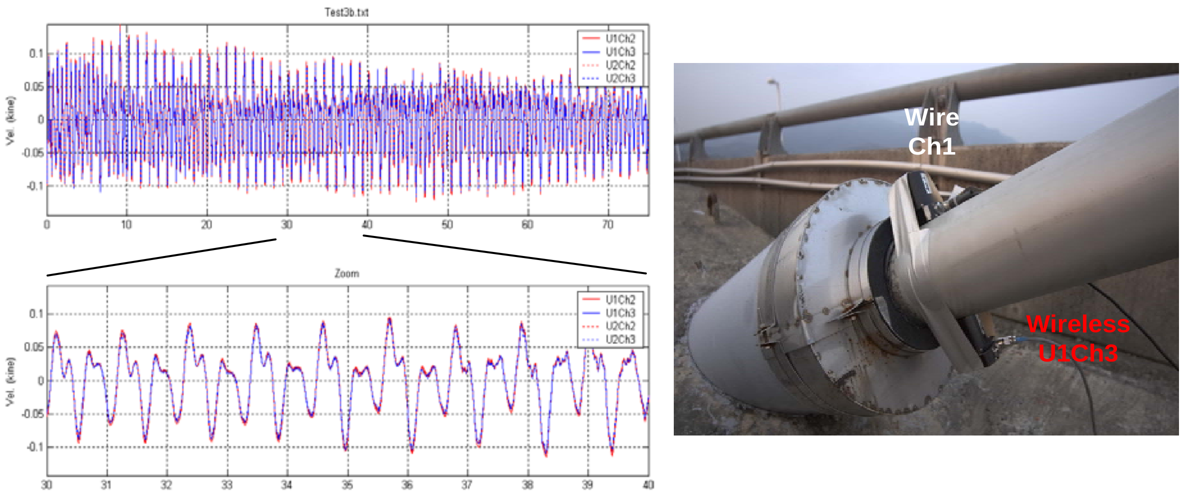


Fig. 4: A signal converter was designed for converting the voltage difference between velocity meter and the sensing unit.

APPLICATION OF WiMMS TO STRUCTURAL CONTROL

A three story steel frame with the installation of a MR-damper in the first story was used to study the application of wireless sensing unit for active structural control. Wireless sensing units was placed on each floor and connected with velocity sensor (or acceleration sensor) to transmit the structural response wirelessly to the receiver at the basement floor. The building



. **Fig. 5 :** Comparison on the recorded velocity from wireless sensing unit and traditional data acquisition system ("Red": wireless, "Blue": traditional).

was tested on shaking table using El Centro earthquake ground motion data as input motion. Fig. 6 shows the schematic diagram of the arrangement of control devices on the structure. Three important devices were needed to control the structure: (1) VCCS: convert the voltage signal (0. volt~ 1.0 volt) to current, (2) DAC: digital to analog converter (from action board to VCCS), (3) Action Board: convert the received commend voltage (16 bit digital signal) to analog signal with 0.~1.0 volt for VCCS. The sensing unit at the bottom floor was also embedded with control algorithm so as to calculate the control voltage to action board, as shown in Fig. 7. The embedded computation algorithm in the sensing unit (at the basement) will cover two major computations: one is to calculate the control force (by multiplying the collected signals with the embedded gain matrix), the other is to convert the commend force to voltage (match with the MR-damper). An action board must be placed between the receiver unit and the VCCS. This action board will conduct the digital to analog converter (0.0~1.0 volts). Fig. 8 shows a picture of the designed action board.

Two different control algorithms were used to calculate the control force (or voltage) for MR-damper: one is the velocity feedback and the other is the acceleration feedback. For velocity feedback control velocity signals at all floor levels were collected wirelessly and multiple by the control gain vector (already embedded) to estimate the required control force.

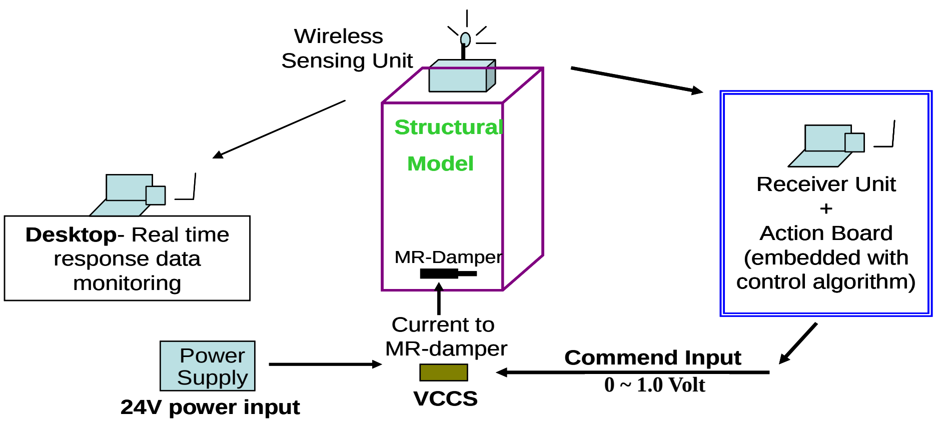


Fig. 6: Overall instrumentation arrangement for structural control test using WiMMS and MR-Damper.

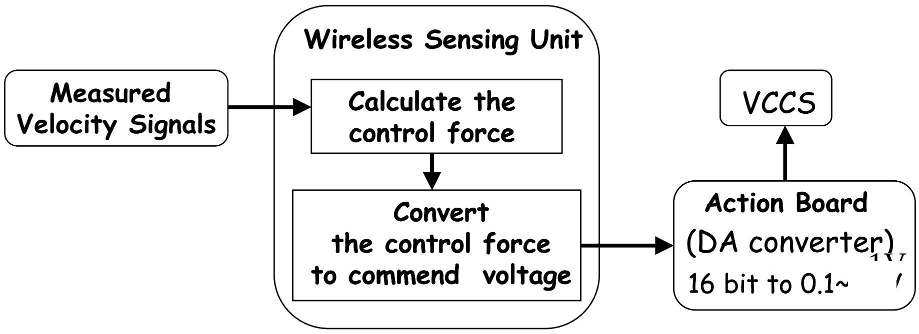


Fig. 7: Configuration between wireless sensing unit and the action board at the 1st floor.

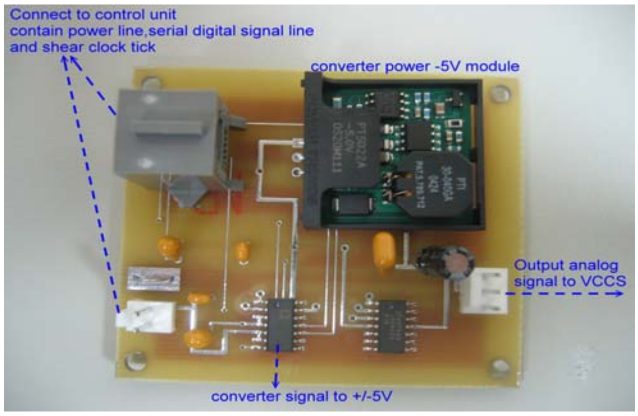


Fig. 8: Action board that convert the 16bit digital voltage to analog signal with 0.~1.0 Volt.

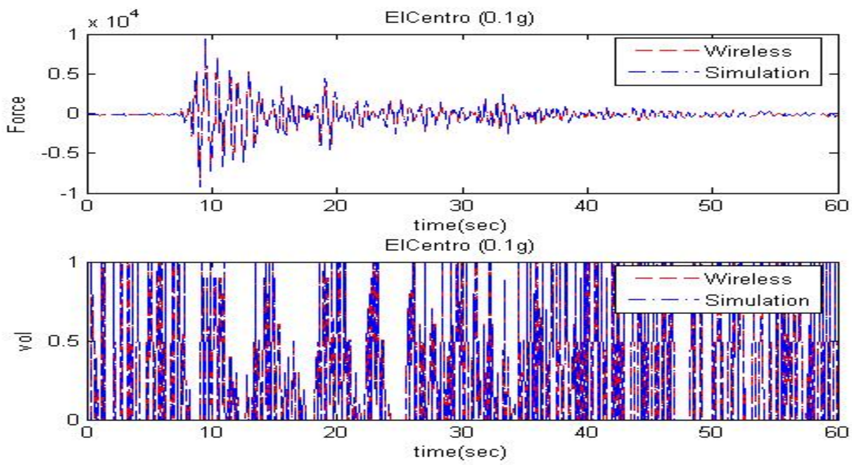


Fig. 9: Comparison on the control force and commend voltage from simulation and wireless sensing unit.

Fig. 9 shows the comparison of the control force and the commend voltage for damper through numerical simulation and the wireless sensing unit. Good agreement was observed. Comparison on the displacement response among un-control structure, numerical simulation result and the control result using wireless control devices is shown in Fig. 10. The result shows that the simulation and the wireless control test are in consistent. This proved that the application of WiMMS for structural control is successful.

CONCLUSIONS

This paper presents the preliminary verification and applicability of wireless modulus monitoring system to monitoring the seismic response of building structure, ambient vibration

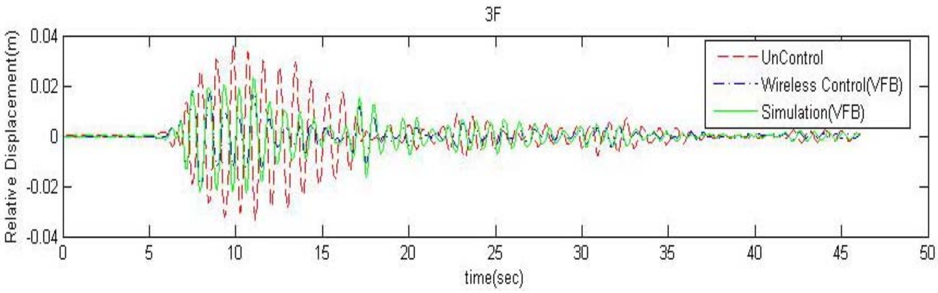


Fig. 10: Comparison on the 3rd floor displacement for case of un-control, simulation, and control using wireless sensing unit

survey of large civil infrastructure and structural control. The results show that the WiMMS can provide a broad applications to monitoring and control of civil infrastructures. With the designed converter different sensor signals can be used as input to the wireless sensing unit for monitoring purpose. For structural control purpose, one can embedded the control gain as well as the control algorithm in the sensing unit. Through this research the structural control can be conducted using wireless sensing unit.

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