A Mobile Wireless Sensor-Based Structural Health Monitoring Technique

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Abstract. Mobile wireless sensor system for structural health monitoring (SHM) has been attracted attention of researchers recently. Compared with static sensors, mobile wireless sensor can provide adaptive spatial resolutions. This paper presents a mobile wireless sensing system for SHM with the aid of smart sensor and mobile robot. The remote-control robot can move on the ferromagnetic surfaces with the magnet-wheeled and place the wireless sensors on the structure accurately by mechanical arm. The structure vibration data is acquired by the wireless sensor and transmit it back to base station. After finished one point test, the robot can pick up the sensor then move to another test points. In this study, a laboratory experiment on sixteen-frame is conducted to test the performance of the mobile sensing system. The results show that the mobile wireless sensor has good potential to be used in SHM in future.

1 Introduction

Wireless smart sensors and networks are the future trend for structural health monitoring (SHM) because they not only provide the similar functionality to traditional wired systems at a much lower installed cost but can also process data autonomously using their embedded microprocessors and software [1-2]. A great amount of efforts have been made in exploring wireless sensing systems for SHM [3-8].

Recently, besides wireless sensing, the mobile sensor networks that implant mobility into traditional sensor networks has been proposed [9, 10], and attracted the interesting of the researchers [11-13]. The advantage of the mobile wireless sensors for SHM is that it can offer flexible architectures, which can have adaptive and high spatial resolutions while using a relatively small number of nodes for SHM [11]. Zhu et al. [11-12] proposed approach of using mobile sensor networks for SHM, they designed a mobile sensor node and used it to collect acceleration response of structure and analyzed the transmissibility function to identify structural damage. Taylor et al. [13] presented a a new wireless sensing network paradigm for structural monitoring applications, which used a mobile-agent to convey both power and data interrogation commands.

This paper presents a mobile wireless sensing system for SHM with the aid of smart sensor and mobile robot. The remote-control robot can move on the ferromagnetic surfaces with the magnet-wheeled and place the wireless sensors on the structure accurately by mechanical arm. Modal testing of the sixteen-frame is conducted to test the performance of the mobile sensing system.

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2 Design of the Mobile wireless sensor system

The mobile wireless sensor system as shown in Fig. 1 is consisted by five parts: the computer, robot, robot controller, wireless sensor node and base station. The detail of the robot is shown in Fig. 2. By using the magnetic force of the magnet on the steel, the robot can be firmly adsorbed on the surface of the steel surface of structure. The robot controller can remote control robot moving at any angle steel surface, carrying a CCD camera on the robot manipulator, multi-degree of freedom cradle head and wireless video transmission module, to provide the operator with a clear, stable image information, the operator image information can view the structure of surface corrosion, cracks and other safety hazards, and can determine the location of wireless acceleration sensors arranged. In the top of the cradle head of the robot, the wireless sensor node can be attached. Through the electromagnet absorption and desorption, the sensor node can be placed on the measurement point of the structure and acquire the vibration data of structure. After finished the data acquisition, the robot controller can remote control the robot to pick up the sensor node and take it to next test point. Repeat this process, all the response of the test points of structure can be obtained.

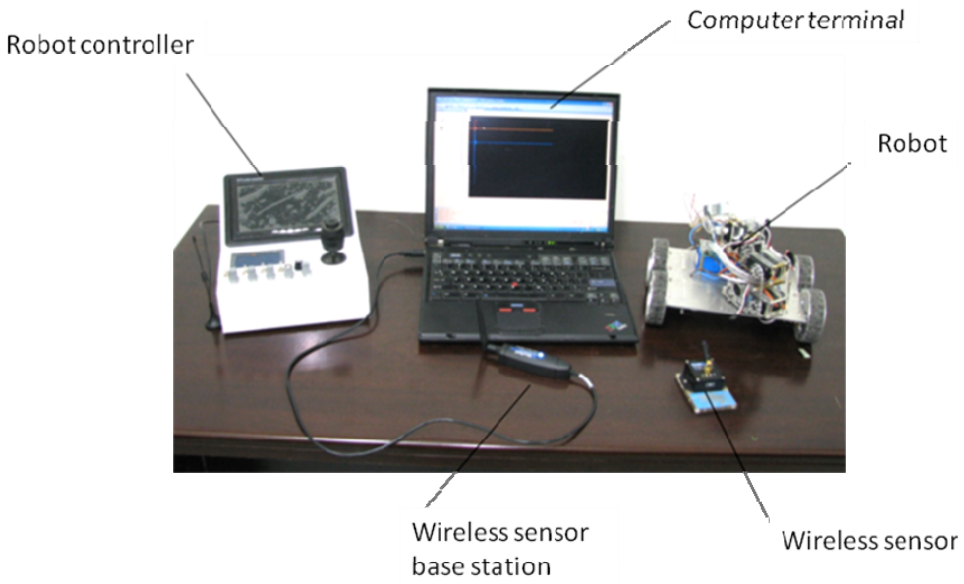


Fig. 1. Mobile wireless sensor data acquisition system

Considering the stability and reliability of the robot, the mechanical structure of the robot must be lightweight, high strength and the adsorption force to be large enough. According to the above requirements, the robot body material is aluminum alloy. The mechanical structure is mainly of two parts: four-wheel drive vehicle body and multi-degree-of-freedom manipulator. The four-wheel drive vehicle body structure use 2A12 high-strength aluminum alloy and the size is 250mm×170mm. The wheel size Φ60×22mm, the outside polygon structure is used to install powerful magnets. The motor use DC worm gear motor with rated voltage of 12V, output shaft of the rated speed for 75r/min and rated power of 25W. The robotic arm using servo motor for providing a driving force, a total of five servo motor provides five degrees of freedom.

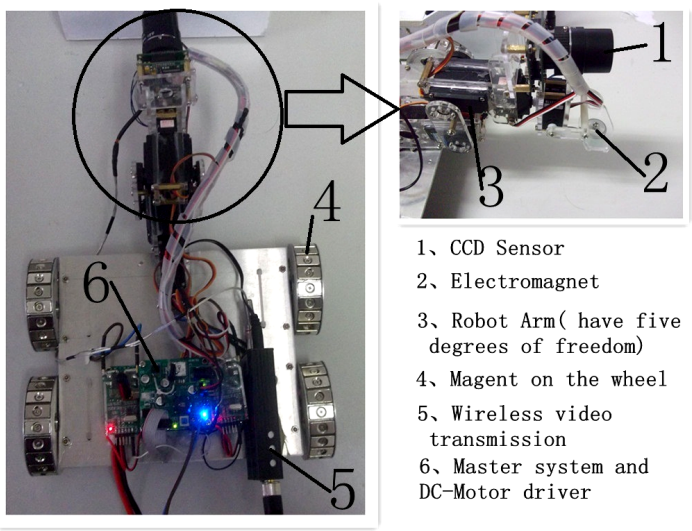
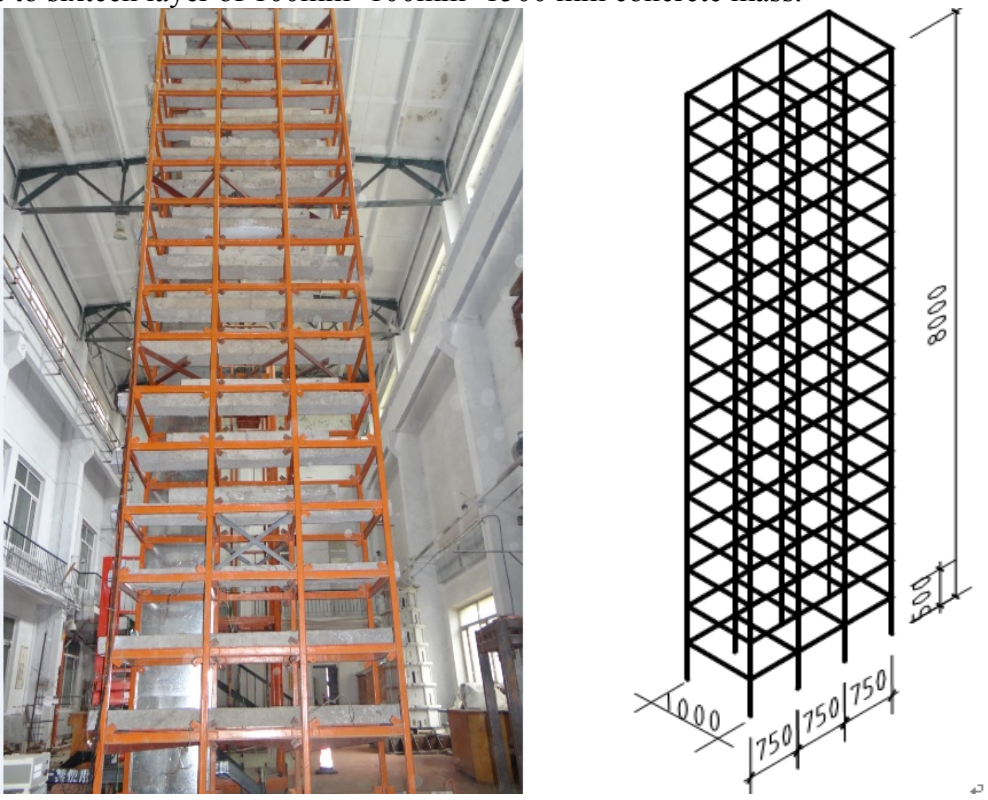


Fig. 2. Picture of the robot

3. Modal Testing using Mobile Wireless Sensor

3.1 Introduction of the experiment model

The experiment model is a frame structure as shown in Fig. 3, which the horizontal span 750 mm×3, longitudinal span 1000 mm and height 500 mm×16. The two to fifteen storey are placed with extra concrete mass with size of 200mm×100mm×2000 mm. The same is to the three to sixteen layer of 100mm×100mm×1500 mm concrete mass.



(a) (b)

Fig. 3. Experimental model: 16 floor framework: (a) model; (b) size of the model

3.2 Modal Test

The purpose of the experiment is to illustrate the modal testing ability of technique base on the mobile wireless sensor. For the robot can move on the frame, a 0.7mm-thick galvanized steel plate is installed on the frame. The famous wireless sensor Imote2 is used for data acquisition. The modal testing procedure can be presented as Fig. 4, which shows that five wireless sensors are installed on the 1-5 floor of the frame and one wireless sensor carried by the robot can move from floor 6-16. The structural is fixed on the shaking table and the white noise excitation is employed in the vibration test and the sampling frequency for wireless sensor is 100Hz.

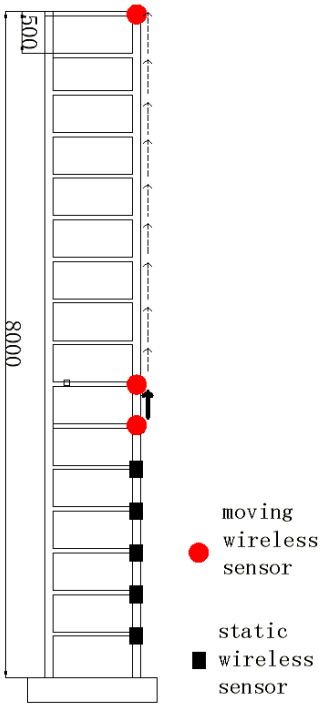


Fig. 4. Modal testing procedure

The robot takes one Imote2 node and moved to the floor which will be test and placed the Imote2 node on the test point as show in Fig. 5. This procedure can be controlled by controller. After finished the data acquisition of this test point, the controller can let the robot pick up the sensor node and move to another test points.

(a) (b)

Fig. 5. Data acquisition by mobile wireless sensor

The measured response of the structure of 7th and 15 floor are shown in Fig. 6,which show about one minute data of the acceleration response.

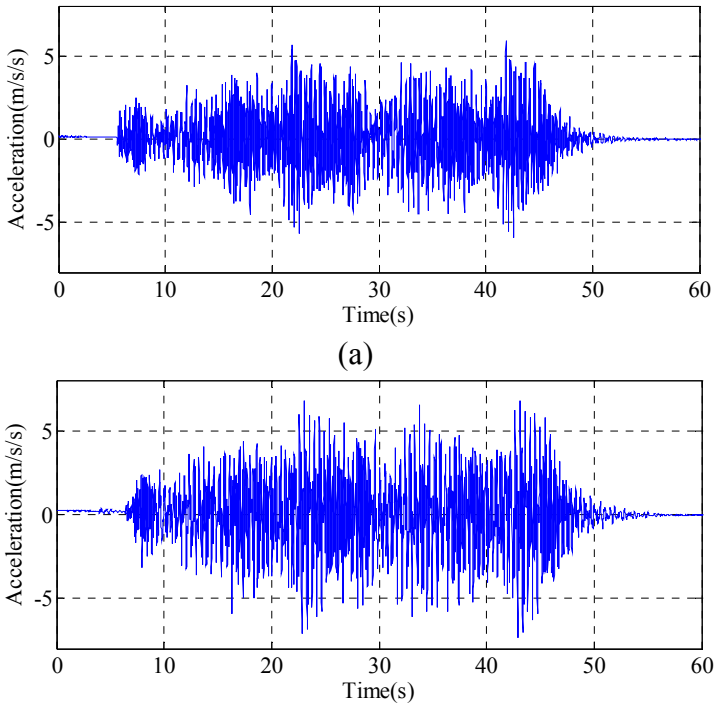


Fig. 7. The measured acceleration response of the structure: (a) the acceleration response 7th floor; (a) the acceleration response 15th floor

To illustrate the accuracy of sensor node placement of the robot, the comparison of the data obtained from the sensor nodes installed by human and robot. The results are shown in Fig. 8, which show the two data is very similar. This illustrates the good ability and accuracy of the sensor placement of the robot.

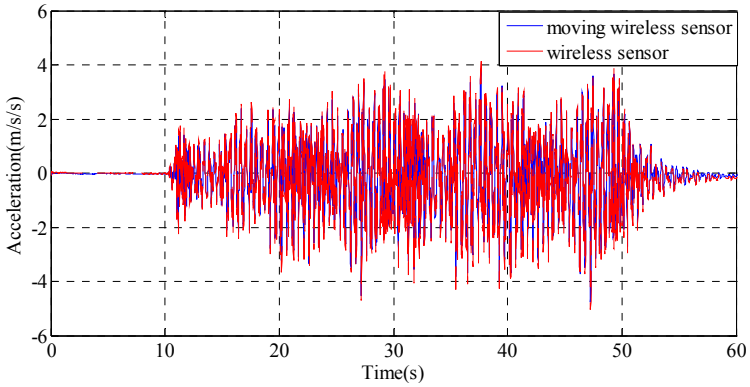


Fig. 8. Comparison of the data obtained from the sensor nodes installed by human and robot.

The structure modal parameters are identified by NExT+ERA methods. The identified frequency damping ratios are shown in Table 1 and the mode shapes are shown in Fig. 9.

Table 1. Identified frequency and damping ratio

Order	**Frequency (Hz)**	**Damping ratio (%)**
1	2.1897	3.62
2	6.5498	0.99
3	8.8560	1.65

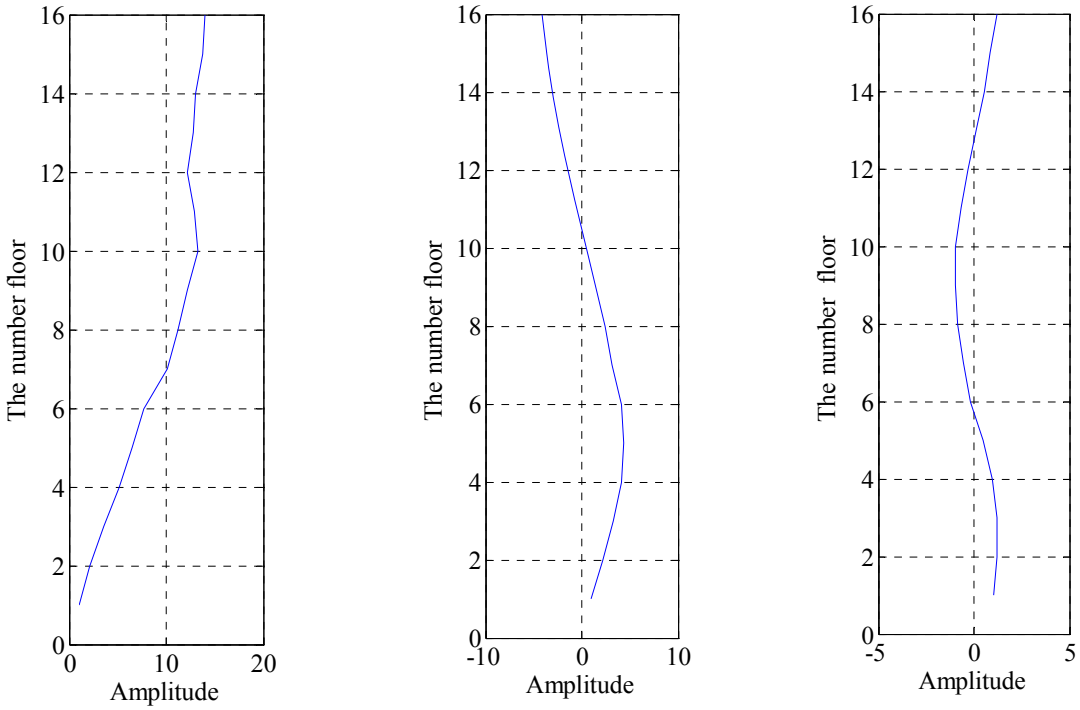


Fig. 9. Identified mode shapes: (a) first mode; (b) second mode; (c) First mode;

4 Conclusions

This paper presents a mobile wireless sensing system for SHM with the aid of smart sensor and mobile robot. The remote-control robot can move on the ferromagnetic surfaces with the magnet-wheeled and place the wireless sensors on the structure accurately by mechanical arm. The structure vibration data is acquired by the wireless sensor and transmit it back to base station. An experiment of a 16-frame structure is carried out to illustrate the ability of this system for model testing. The results show that the mobile robot can place the wireless sensor exactly. Using this mobile system, spatial density testing can conducted and the mode shapes tested in this experiment shown that this approach can work well.

But the mobile system presented in the paper is developed for a proof-of-concept study in laboratory. Significant efforts will be needed for increasing the robust of the system for actual civil structures. Otherwise, the operating system also will be improved to more smart and have data analysis ability.

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