16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 4037

Registration Code: S-I1463099185

MEASUREMENT OF VIBRATION CHARACTERISTIC OF A BRIDGE USING PIEZOELECTRIC BOLT-TYPE SENSORS

C. Cuadra(1), N. Shimoi(2)

(1) Associate Professor, Faculty of System Science and Technology, Akita Prefectural University, Japan,carlos@akita-pu.ac.jp
(2) Professor, Faculty of System Science and Technology, Akita Prefectural University, Japan,shimoi@akita-pu.ac.jp

Abstract

Piezoelectric bolt-type sensor was used to estimate predominant frequencies of vertical vibration of bridge located at Yurihonjo city, Japan. The equipment was first tested to observe the dynamic response of a provisional bridge. Then the measurement system was applied to evaluate the dynamic response of a target bridge. This structure is a continuous beam type bridge with steel beams of variable sections and reinforced concrete slabs to support the asphalt carpet. The bridge consists of seven spans with a total length of 256 m. The experimental measurements were performed on the first span near the left embankment. Natural periods of vibration are obtained by Fourier analysis of recorded signals from piezoelectric sensors. Since piezoelectric sensor emits a signal when a change in the stress condition occurs, the sensor was setup at the support of the bridge where large changes in the stress level is expected to occur. Signals from piezoelectric bolt sensors are transmitted to computer by means of a wireless module which contains a microcomputer board. The proposed system is simple and it is easy to install in-situ. Former measurements systems require a lot of equipment like energy generator, and signal amplifiers as is the case of measurements using accelerometers. For comparison measurements with conventional accelerometers were also performed. Responses were captured appropriately using the proposed system and they are comparable with responses obtained from accelerometers. The general response pattern was obtained appropriately however, it is necessary to improve the accuracy of the proposed system to have more reliable data. This experimental verification of dynamic characteristics of the target bridge will be useful to construct a reliable analytical model to perform seismic response analysis of the bridge.

Keywords: Piezoelectric sensor, Structural monitoring, Bridge, Dynamic characteristics

1. Introduction

Many old bridges in Japan require an evaluation of their structural integrity to guarantee a safer use of these structures. The Ministry of Land and Transportation of Japan has performed a study of the vulnerability of bridges and 121 cases of bridges in danger have been reported. The risk of the bridges is due to the deterioration of aged concrete bridges (weathering) and corrosion of steel bridges. Many of these bridges have more of 50 years of age and consequently present serious deterioration. On the other hand in the 80thies of the last century constructions of large projects of building and bridges were initiated and therefore high demand of materials, in special for reinforced concrete structures, induced the used of sea sand which contains salts that in reaction with water and cement originates the corrosion of the steel reinforcement. Outside Japan an example of the necessity of health monitoring was evident in the collapse of the bridge I-35W on Mississippi River in United States of America. During the evening rush hour on August 1, 2007, the bridge suddenly collapsed, killing 13 people and injuring 145. To prevent damages it is believed that a real-time structural health monitoring could help to this task.

A continuous or real time structural health monitoring could help to prevent damages. Monitoring systems already exist however they are in general designed to be installed in new structures and are expensive. For existing old structures, simple and cheap sensor systems are required. Then in this research piezoelectric material is employed to develop a new sensor which can be easily installed in target structure and since piezoelectric material does not need energy to emit voltage signals the cost of monitoring could be reduced. This new sensor that is based on piezoelectric cable inserted into a bolt shape cover was developed and its applicability to perform health monitoring of structures is verified by means of a series of measurements on vibration of a target bridge. The selected bridge is located at Yurihonjo city, Akita prefecture, Japan. Results obtained with this new simple smart sensor are comparable with those obtained with more sophisticated and expensive commercial sensors.

2. Measurement device

The piezoelectric-bolt sensor is shown in Fig. 1, and contains in its interior a piezoelectric cable which is covered by urethane resin. Then the nominal diameter of the bolt sensor is 15 mm and its longitude is 80 mm. However to fix the sensor an external metal envelope, forming the bolt spiral, covers the system and the nominal diameter results in 20 mm (M20). This proposed simple sensor can measure strain by the change of the voltage in the inner piezoelectric cable when this cable is deformed by an external action. Therefore relative displacements and vibration of bridge joints can be easily measured. Moreover, the characteristics of the sensor like sampling frequency permits to send the signal to a four channels computer board for automatic data acquisition. In this way signals from four sensors can be recorded simultaneously with a direct input computer board.

Fig. 1 – Piezoelectric bolt sensor

For in-situ test on bridge structure, the sensor was installed together with a high precision commercial accelerometer to compare both results. For the proposed sensor data was recorded using a wireless system (Zigbee wireless module). Source energy (lithium battery pack Lipo2000mAh) is required for the board that receives the signal from the sensor and transmits it to the computer for data acquisition. Personal computer required its own source of energy for acquisition and posterior data processing. Fig. 2 shows the general scheme of the data acquisition system using the proposed sensor.

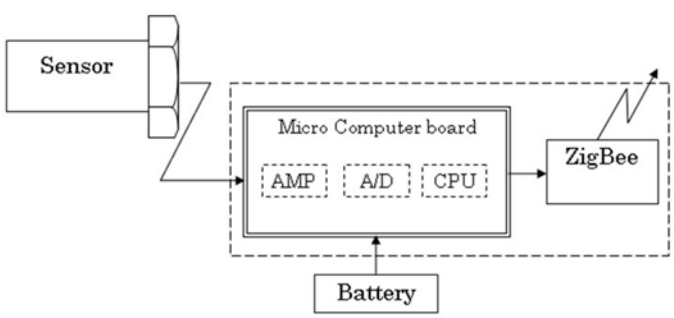

Fig. 2 – Scheme of measurement systems

Fig. 3 shows the measurement system for a bridge. In this case the sensor is connected to a radio unit which sends a wireless signal to a controller connected to a computer (Fig. 3(a)). The sensor itself does not need input energy to emit its response however radio unit requires a source of energy. Signals from sensor can be monitored from a control room as is shown in Fig. 3(b). In this research a prefabricated portable room was installed near the target bridge to perform measurements.

3(a) Sensor unit 3(b) Control room

Fig. 3 – Sensor signal transmission and general layout of control room

3. Measurement of bridge vibration

As a preliminary measurement, a temporary bridge located at Yurihonjo city, Akita Prefecture, Japan was selected, and sensor was installed in a joint of the bridge as is shown in Fig. 4. This bridge spans over the Koyoshi river and has 175 m in total length. For comparison high precision accelerometers were also installed and measurements were performed during 3 days from 9:00 am to 4:00 pm. In addition video recorder was also installed to verify the type of vehicles which produce the vibration of the bridge.

Fig. 4 – Temporary bridge for preliminary measurements

Fig. 5 shows the comparison of measurements performed at the temporary bridge. The results from simple smart bolt sensor and results from high precision 3D accelerometers are comparable and general tendency which permits to identify the vibration originated by various kind of vehicles were obtained. The types of vehicles were identified by the analysis of the video record that was synchronized with the measurements devices. For example, the pass of heavy vehicle like a garbage car was clearly detected. Therefore, by comparison it can be stated that the remarkable vibration due to the vehicle passing is well captured by the proposed sensor and applicability for real time vibration monitoring has been proved.

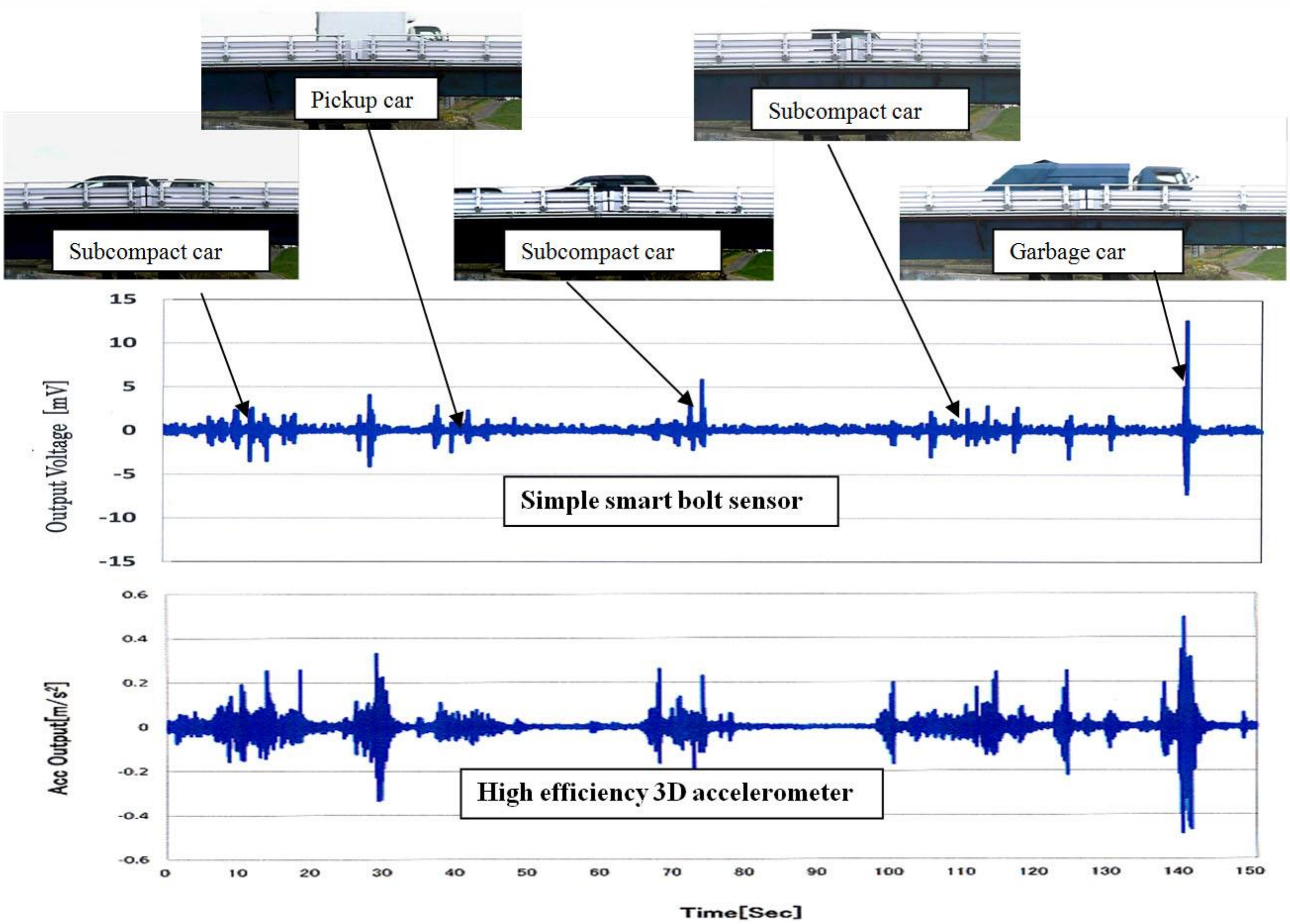

Fig. 5 – Comparison of measurement results from simple smart bolt sensor with those obtained from high efficiency 3D accelerometer during structural monitoring of a bridge.

After the preliminary measurement that verifies the applicability of the proposed system, a target bridge which is shown in Fig. 6 was selected to estimate its dynamic properties in special the frequency or period of vibration. This bridge is called Asuka Oohashi constructed in the year 1979 and spans over the Koyoshi river with a total length of 256 m. Fig. 7 shows the dimensions of the target bridge. The first span of 31 m. of length and located near the left abutment was chosen for measurements with the piezoelectric sensors (span ①). The target structure is a girder type bridge which is composed of steel beams that supports a reinforced concrete slab.

Fig. 6 – Asuka bridge chosen for measurements with piezoelectric sensors

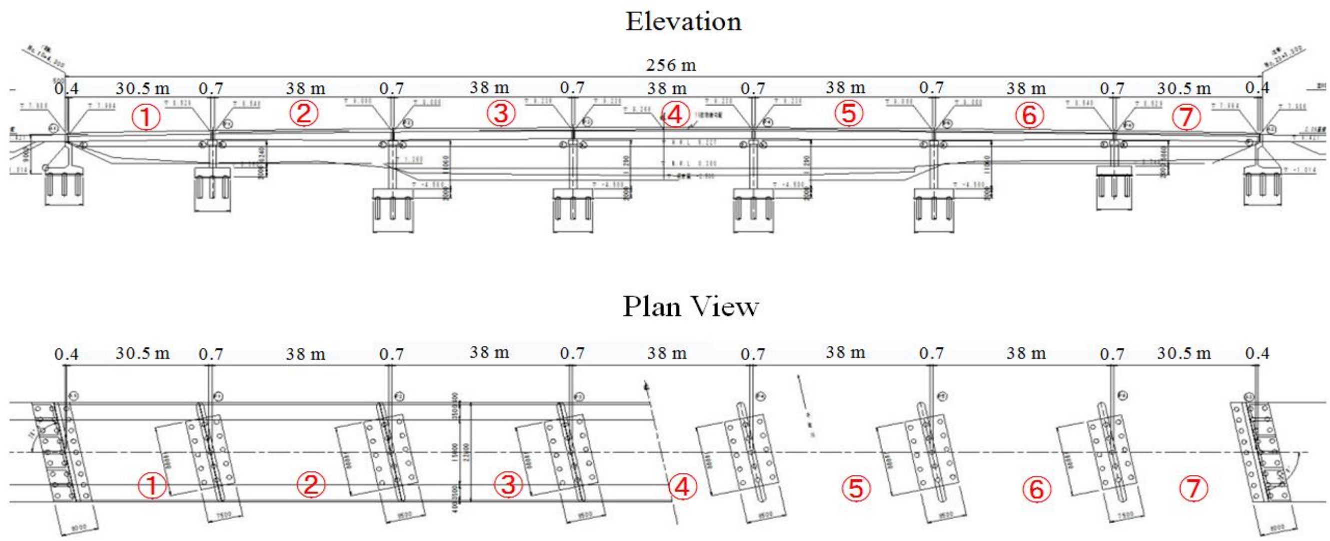

Fig. 7 – Dimensions of target bridge

Points of vibration measurements on selected span are shown in Fig. 8. Bolt type sensors were located at seven points of measurements together with accelerometers to compare both results. In addition at middle of span a laser displacement transducer was setup near point No. 7.

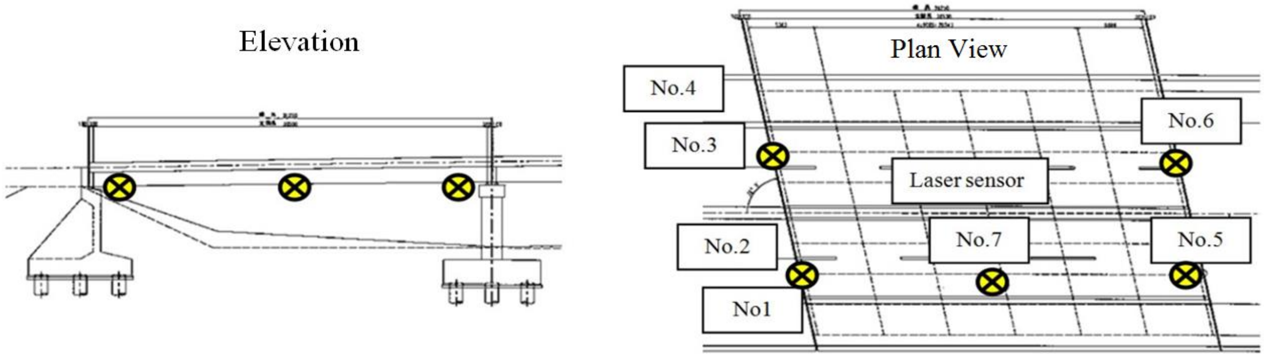

Fig. 8 – General setup of points of measurements

Figure 9 shows some details of sensors setup. Basically, relative displacements between girders and support structure were measured at each point. For this purpose, sensors were fixed firmly to girder flange with its end in contact with support surface. Sensor 1, 2, 3, 4, 5 and 6 were setup in this way as can be observed in Figures 4(a) and 4(b).

(a) Sensor No1,3 and No2,4 (b) Sensor No5,No6

Fig. 9 – General setup of points of measurements

From recorded signals, predominant frequencies were obtained by Fourier analysis. In Fig. 10 Fourier spectrum for signals from point No. 1 to No. 6 are shown. Upper part of each figure corresponds to accelerometers results and bottom part corresponds to proposed sensor results. Results for point No. 1, No. 2 and No. 4 show good agreement between accelerometer results and proposed sensor results. The difference of results at point No. 5 and at point No. 6 it is believed that is due that proposed sensors and accelerometers are not set up at same location. However in the Fourier spectrum for proposed sensor a second peak near 3.6 Hz is observed which is comparable with the predominant frequencies obtained from accelerometers.

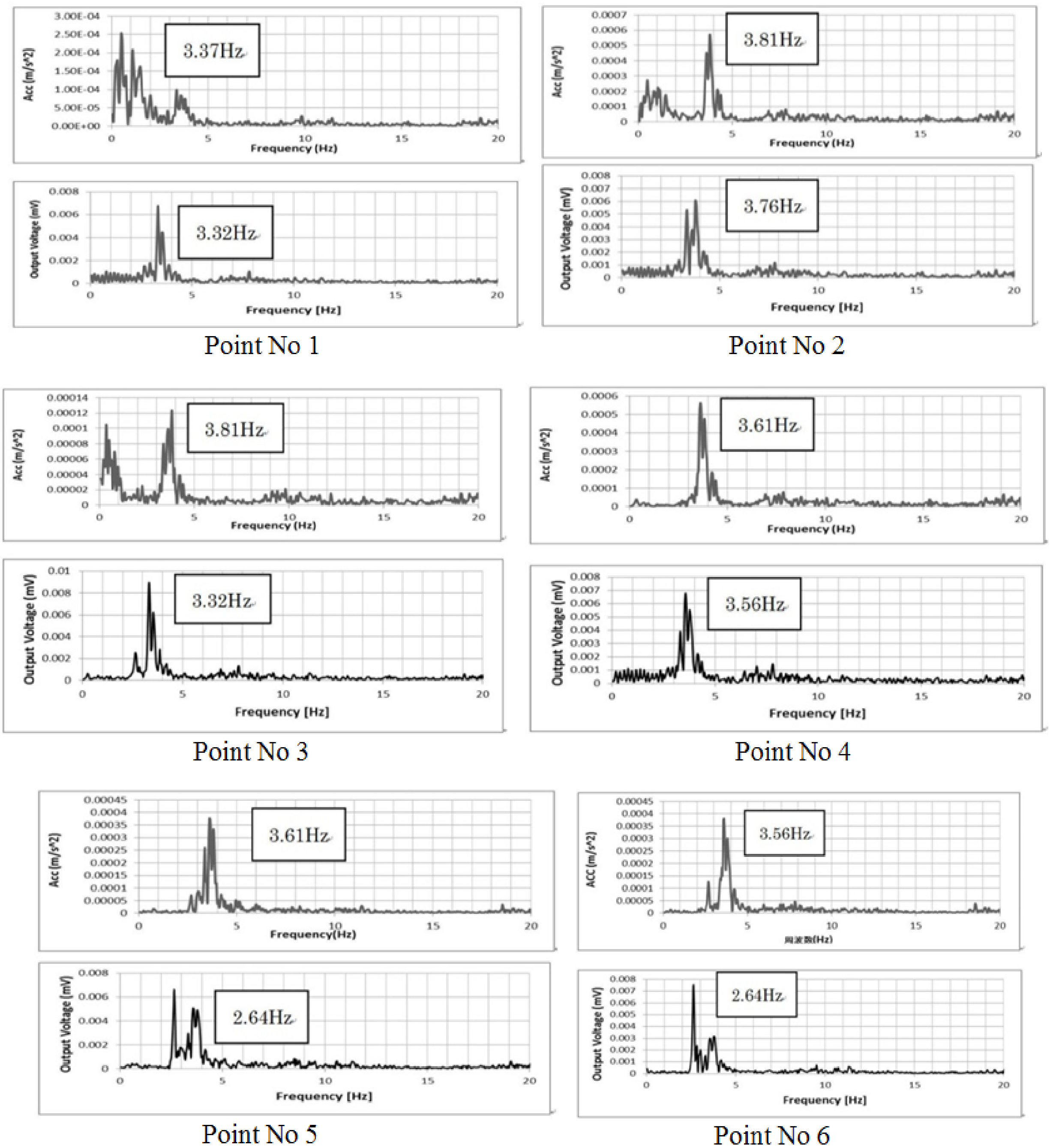

Fig. 10 – Predominant frequencies from Fourier analysis

4. Conclusions

A new smart simple piezoelectric sensor and its corresponding data acquisition system were developed to be used for real time structural health monitoring of structures.

First, proposed piezoelectric sensor was installed in a joint of a temporary bridge and measurements of the output voltage have permitted to infer the amplitude and frequency of the vibration and therefore it is possible to obtain the dynamic characteristics of structures under investigation. The response of the proposed sensor for different type of vehicles passing on this temporary bridge is similar to that detected by means of high sensitivity accelerometers.

Installation of the system in selected portion of an actual bridge structure has permit to perform the monitoring of the structural response to obtain its free vibration characteristics. The applicability of this new piezoelectric sensor for structural health monitoring and estimation of dynamic characteristics of a bridge structure was verified. Simultaneously commercial accelerometers were used for vibration measurements to compare with those measurements using proposed system. In general predominant frequencies obtained from in-situ measurements using accelerometers and proposed bolt sensors show good agreement.

5. Acknowledgements

The authors acknowledge Japan Society for the Promotion of Science for the Grants-in-Aid for Scientific Research on Smart Structure Sensing System Using Piezoelectric Cable, under which this research was conducted.

5. References

[1] Ministry of Land, Infrastructure and Transports report: Research on upgrading of soundness evaluation method for highway PC bridges. Technical Note of. National Institute for Land and Infrastructure Management, No.623, pp6--14, (2010), (in Japanese).

[2] T. Okabayashi, T. Okumatsu, and Y. Nakamiya: Experimental Study on Structural Damage Detection Using the High Accurate Structural Vibration-Estimation System, Journal of Structural Engineering A, Vol.51A, pp.479--490 (2005), (in Japanese).

[3] Y. Nitta, K. Imamoto, and A. Nishitani: Structural Health Monitoring Utilizing Piezoelectric Cable, Summaries of technical papers of Annual Meeting Architectural Institute of Japan. B-2, Structures II, Structural dynamics nuclear power plants 2006, pp. 891--892, (2006), (in Japanese).

[4] Carlos Cuadra; "Vibration Characteristics of an Old Steel Bridge" Sustainable Infrastructure Environment Friendly, Safe and Resource Efficient, IABSE Symposium Bangkok 2009, Abstract pp. 246-247. CD-ROM paper.

[5] C. H. Cuadra, J. Meguro; "Evaluation of the dynamic characteristics of a base-isolated low-rise RC building after the Great East Japan Earthquake", Proceedings of the 15th World Conference on Earthquake Engineering, September 24-28, 2012, Lisbon, Portugal, Paper No. 1284.

[6] Katsumi WASAKI, Nobuhiro SHIMOI, "A Practice of Smart Sensing System for Buried Mines Detecting based on Active Infrared Thermography Approach" International Journal of Computational Intelligence: Theory and Practice , 4(1)pp29-37(2009)

[7] Nobuhiro.Shimoi,Yoshihiro Takita,"Remote mine sensing technology using a Mobile Wheeled Robot RAT-1", Proceedings of the International Conference on Control Automation and Systems. ICCAS 2010, pp TE06-4(5)(2010.10)

[8] Carlos H. Cuadra, Nobuhiro Shimoi, Tetsuya Nishida and Masahiro Saijo; "Estimation of Dynamic Properties of Traditional Wooden Structures Using New Bolt Sensor", 13th International Conference on Control, Automation and Systems (ICCAS 2013), Oct. 20-23, 2013, Kimdaejung Convention Center, Gwangju, Korea.Hidalgo P (2009). Personal communication.