International Journal of Hybrid Information Technology
Vol. 7, No. 6 (2014), pp. 123-132
http://dx.doi.org/10.14257/ijhit.2014.7.6.10

A Real-Time Vibration Frequency Measurement System of Bridge Pier

Yao-Ming Hong[1], Jian-Rong Zeng[2], Yao-Chiang Kan[3] and Hsueh-Chun Lin[4]

[1]Associate Professor, Department of Landscape Architecture and Environmental Planning, MingDao University, Changhua, Taiwan
[2]University Student, Department of Landscape Architecture and Environmental Planning, MingDao University, Changhua, Taiwan
[3]Associate Professor, Department of Communications Engineering, Yuan Ze University, Taoyuan, Taiwan
[4]Associate Professor, Department of Health Risk Management, China Medical University, Taichung, Taiwan
blueway@mdu.edu.tw[1] , peter1128350@kimo.com[2] , yckan54@gmail.com[3], snowhc.lin@gmail.com[4]

Abstract

This study developed a real-time remote monitoring system (RTRMS) to receive the vibration frequency of bridge pier. The system included a front station and a middle station. A multi-hop wireless routing is employed to transmit the data from the front to the middle station. The front station includes a receiver equipped to receive the vibration frequency, and a wireless sensor network to transmit the data. The middle station is designed by an embedded system for storing the data. The pressure test shows that the loss rate of received data is less than 0.6%. The consuming power of one day is 3 ampere hours in the front station and 30 ampere hours in the middle station if the 12 voltage battery is used.

Keywords: *vibration frequency, real-time remote monitoring system, wireless sensor network*

1. Introduction

Scour on bridges usually damages piers and abutments, and is a major risk causing many bridge failures [1]. The most common bridge failures in America occurred as floods scoured out bed materials from bridge foundations nearby [2]. For example, the well-known 1993 midwest flood hit the upper Mississippi basin of the USA and caused 23 bridge failures. The modes of bridge failures were classified: fourteen by abutment scour, two by pier scour, three by the pier and abutment scour, two by lateral bank migration, one by debris load, and one by an unknown cause. In New Zealand, at least one serious bridge failure each year was yielded by the scoured bridge foundations [3]. In Taiwan, Typhoon Morakot (August 6-9, 2009) attacked Gaoping River Basin and severely damaged the bridge, where the modes of bridge failure can be subjected into four types: flood induced scour, debris flow, woody debris, and dammed lake break [4].

Therefore, local scour occurred at the bridge pier should be monitored during the flood period to supply the decision basis of bridge damage. For example, a Scour Monitoring Decision Framework (SMDF) was allowed to select the best technologies for specific sites [5]. Five bridges were also tested by the SMDF in a case-study for type demonstration; work plans for two of the sites were developed for demonstrating the deployed instrumentation.

ISSN: 1738-9968 IJHIT

Zarafshan *et al.* [1] measured the fundamental frequency of vibration of a rod embedded in the riverbed to detect the scour depth. The sensor uses a single fiber-optic Bragg grating (FBG) sensor for transduction of the vibration frequency. Hong *et al.* [6] developed a vibration frequency measurement equipment was to receive the vibration frequency of bridge pier, which can be used to predict the scour depth of bridge pier in the future.

The progress of micro-electro-mechanical system (MEMS) enables the application of wireless sensor networks (WSN) in the environmental monitoring field. Based on the MEMS technology, a wireless scour monitoring system has been established and examined to measure the scouring and deposition process due to variation of water levels at a bridge pier [7]. A Mote-Integrated Converter Module (MICM) is designed and implemented to servo velocity sensors (SVS) of bridge pier and WSN [8]. Moreover, information Management using mobile phone in WSN is the commonest factor. Mobile phone will be the main access point in WSN. The system will be as simple as possible providing all the facilities those are available in web based rather PC based applications regarding this [9].

In this study, the self-developed MICM was expanded to a Real-Time Vibration Frequency Measurement System (RTVFMS). An embedded system was involved within the system to store monitoring data immediately. The power consumption of equipment was calculated to estimate the battery power required during the flood period. The data loss rate of RTVFMS was also tested to ensure the validity of received information. Finally, a reliable RTVFMS was established to monitor the bridge scour.

2. Vibration Frequency Measurement System

The development of RTVFNS includes two steps. Firstly, this study designed the structure of RTVFMS, and combined all of the necessary equipment into the system. Secondly, the system should be tested and modified to confirm the stabilization.

2.1. System Architecture and Equipment

Figure 1 displays the system architecture, which is similar to the system developed by Hong *et al.* [10]. The system includes SVS, infrastructure nodes, the gateway, a web interface, and a decision making center. Firstly, the SVS detected velocity of the vibrated bridge pier, while the data can be broadcasted by infrastructure nodes to the gateway by multi-hop transmission. The gateway stores the data and transmits to the web interface through general packet radio service (GPRS) system. The Matlab program will transform the sensed data as vibration frequency for estimating the scour depth of bridge pier. The decision making center then can determine the timing of the bridge closure based on the criterion of scour depth as well as release the alert to car drivers. The equipment designed in the proposed system is illustrated as follows.

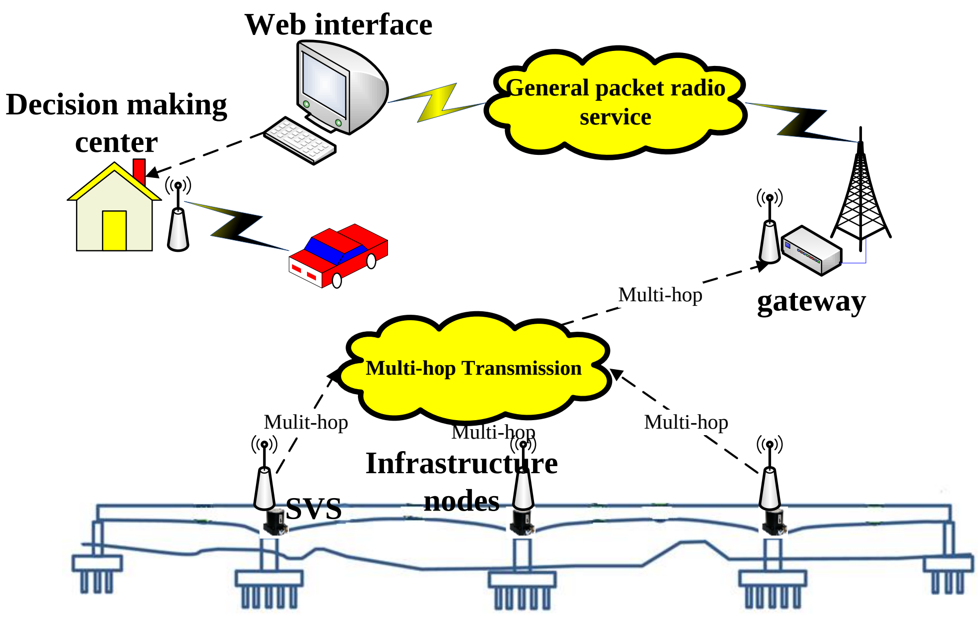


Figure 1. System Architecture of RTVFMS

(1) Sensors: The servo velocity seismometer NO. VSE-15D (Figure 2 (a)) made by the TOKYO SOKUSHIN CO was adopted as the SVS. The sensor adopted the voltage value to represent the velocity data, which will be transfer to the gateway by infrastructure node.

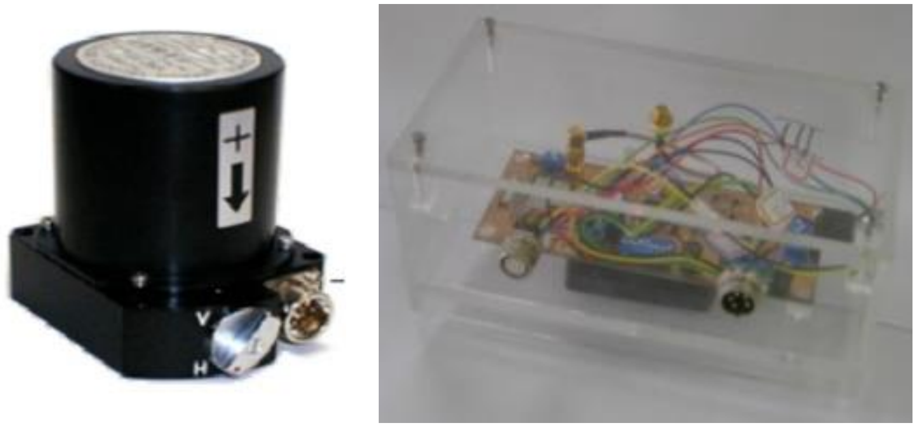
(2) Infrastructure node: Tmote mini plus developed by Moteiv Corporation was used as the infrastructure node. This study developed a circuit board to connect the SVS and mote ((Figure 2 (b)). With the built in 24-bit analog to digital converter (ADC), Tmote mini plus can deliver the sensing data to the gateway by multi-hop transmission.

(3) Gateway: Tmote Sky (Figure 3 (a)) developed by Moteiv Corporation was used to receive the sensor data from the infrastructure nodes. In addition, this study adopted a programmable automation controller (PAC) NO. XP-8401 (Figure 3(b)) developed by ICP DAS to store the sensing data temporally. GPRS modem can also connect the PAC to deliver the data to the web interface.

2.2. Equipment Installation

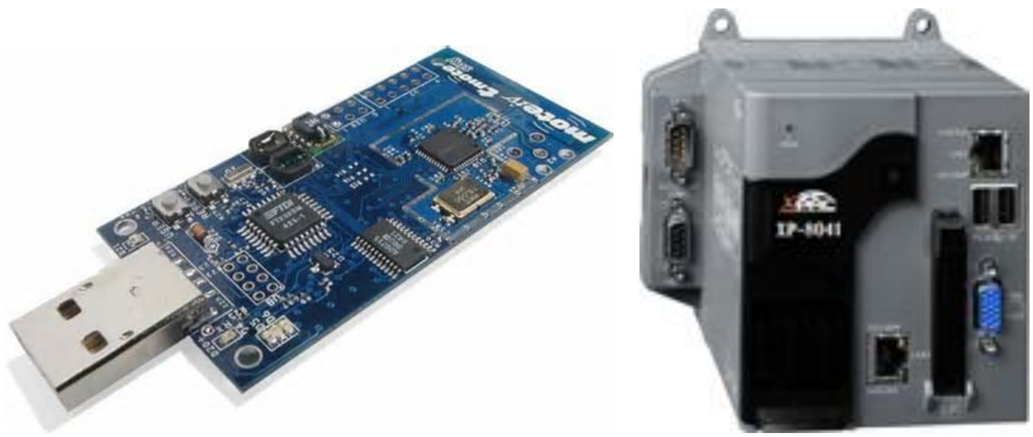
The TAJIMI-8Pin cable plug is used to connect the SVS and the circuit board shown in Figure 4 to form the infrastructure, which can receive the message of bridge vibration and then transmit to the gateway.

The Universal Serial Bus (USB) is used to connect the Tmote Sky and XP-8401 shown in Figure 5 to make up the gateway. During the laboratory test stage, we add power transformer to supply the equipment’s power.



(a) VSE-15D (b) Infrastructure Node

Figure 2. Sensor and Infrastructure Node



(a) Tmote Sky (b) XP-8401

Figure 3. The Equipment Used in the System

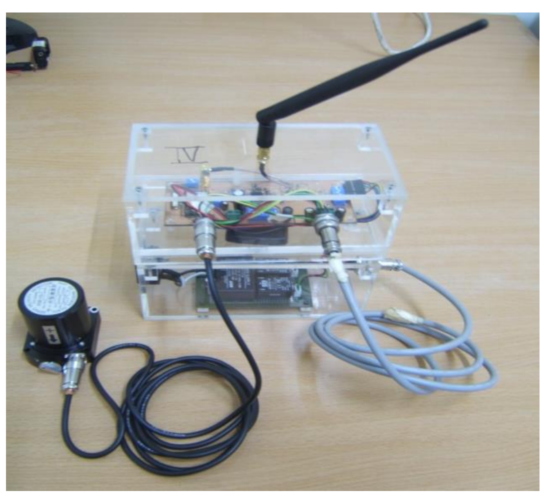


Figure 4. The Installation of Sensor and Infrastructure Node

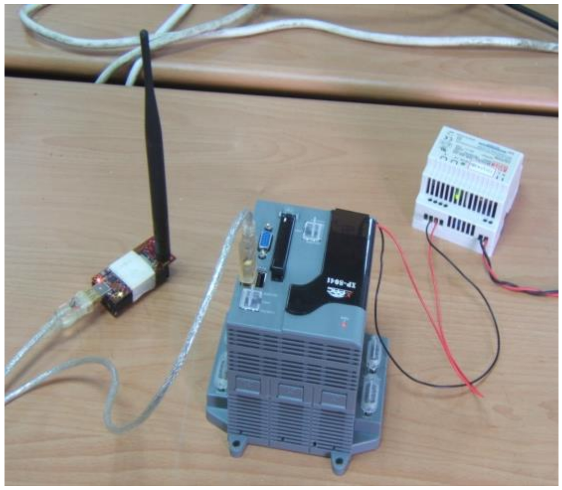


Figure 5. The Gateway Combination

2.3. The Receiving Programming Interface

This study adopted Visual Basic to develop a Graphic User Interface (GUI) to receive the infrastructure data shown in Figure 6. This GUI program was installed in the gateway (XP-8401), which can adjust the necessary conditions to receive the sensing data.

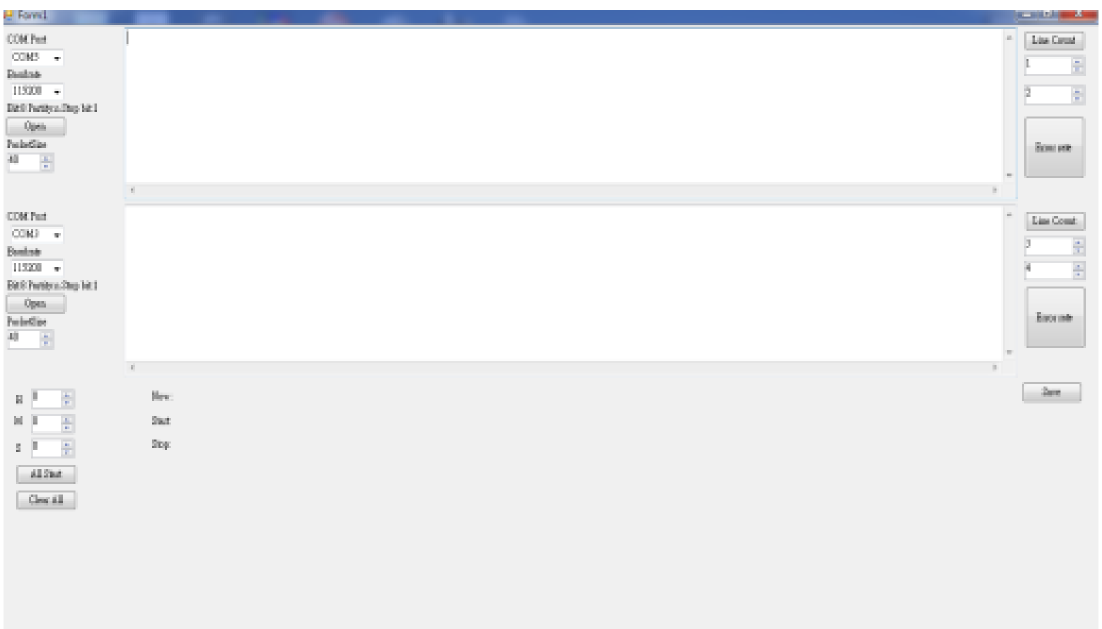


Figure 6. The Receiving Programming Interface in the Gateway

3. Laboratory Test of RTVFMS

The purpose of laboratory test is to estimate the reliability of data transmission, the quality of measurement, and the power consumption.

3.1. The Packet Loss Rate

The packet loss rate of data transmission between infrastructure node and gateway should be small, so as the packets quantities received at the gateway are enough to estimate the vibration frequency. The packet loss rate L is defined as:

$$L = (1-(A/B)) \times 100\% \quad (1)$$

where A is the amount of receiving packets in the gateway; B is the amount of outgoing packets in the infrastructure node. The experiment was executed in a water circulation channel shown in Figure 7. The SVS was put on the bridge pier model on the channel (Figure 8).

The infrastructure node was set up to deliver 50 packets every second, and the experimental time is one hour. The total outgoing packets are 183600. After one hour test, the total reception packets are 182546, and the loss rate L = 0.57%, which is really small. In conclusion, the system developed by this study can deliver enough sensing data to the decision making center for further analysis.

Figure 7. Water Circulation Channel

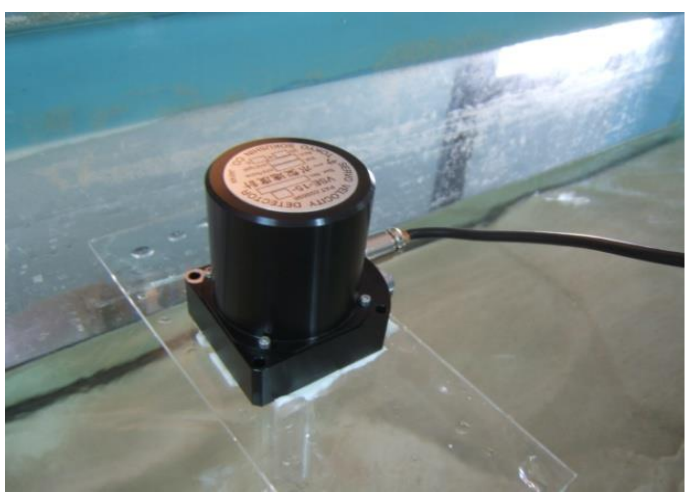


Figure 8. SVS on the Bridge Pier Model

3.2. The Analysis of Sensing Data

The original data perform the velocity as shown in Figure 9. This study adopted Matlab software to calculate the vibration frequency. Firstly, the acceleration, shown in Figure 9, can be converted by velocity. Secondly, the Fast Fourier Transform (FFT) is adopted to find vibration frequency after filtering noises.

After the FFT, this study draws the distribution of vibration frequency, in which the most frequent data are the main vibration frequency. From Figure 10, the experimental outcomes show the main vibration frequency = 15.24 Hz. Many studies have proved that the main vibration frequency will be changed by the land cover depth of bridge pier.

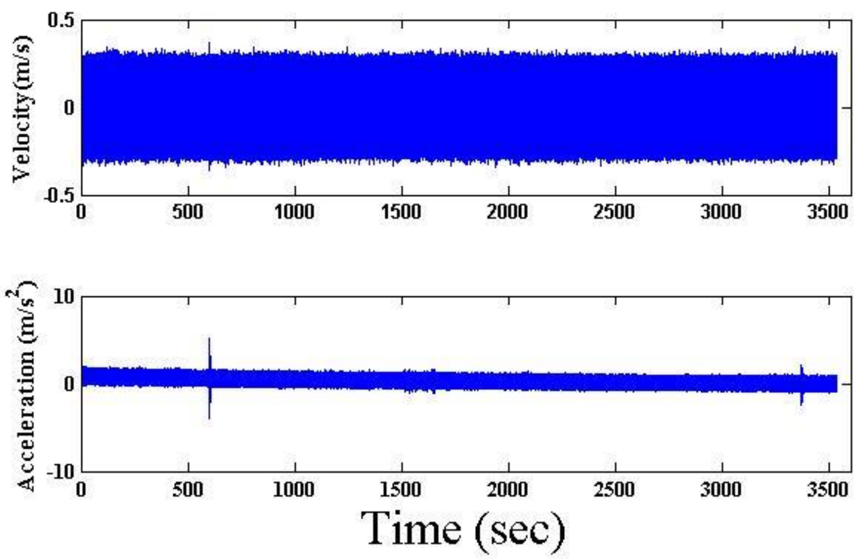


Figure 9. The Velocity and Acceleration of Sensing Data during One Hour

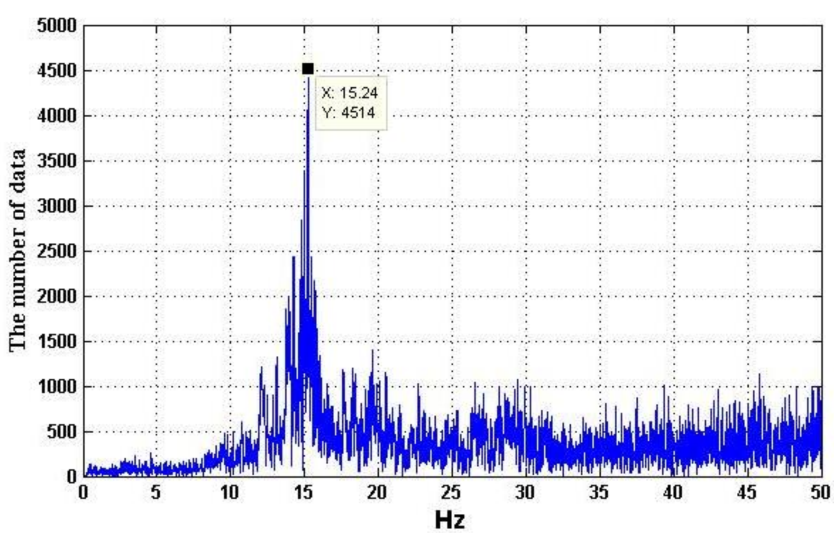


Figure 10. The Frequency Distribution of Bridge Vibration

3.3. The Power Consumption in the Field

The power supply in the field should be enough to support the equipment operation during the monitoring period. The calculation method can be expressed as follows [11]

$$P = I \times V \quad (1)$$

where P is the consumption power(Walt); I is the consumption Ampere; V is the Voltage. The energy consumption is

$$E = P \times T \quad (2)$$

where E is the consumption energy(Joule); T is the monitoring duration; The Ampere-hour of battery (Ah) can be calculated by

$$Ah = E/3600V_b \quad (3)$$

where V_b is the battery voltage, where the 12 V is used in this study. Table 1 displays the energy consumption of equipment in the field and the selection of battery power. The power consumption of sensor and infrastructure node is 3.1 Ah for one day, and that of the gateway is 28.9 Ah. For the conservative estimation, this study suggested 6Ah for sensor and infrastructure node, and 60 Ah for gateway.

Table 1. The Energy Consumption of Equipments and the Battery Selection in the Field

Location	Equipment	Voltage V	Ampere I	Power P	Energy E	Sum	Ampere-hour	Used Ah
Sensor & Infrastructure Node	VES-15D1	15	0.055	0.825	71280	133920	3.1	6
	Converter Module	5	0.145	0.725	62640			
Gateway	XP-8401	24	0.6	14.4	1244160	1249811	28.9	60
	Tmote Sky	3	0.0218	0.0654	5650.56			

4. Conclusion

This study developed a real-time vibration frequency measurement system of bridge pier by combining servo velocity sensors, wireless sensor network and embedded system. The infrastructure node was developed by a circuit board to connect the sensor and WSN. The gateway is based on the embedded system XP-8401 to connect the WSN, to storage the data, and to transmit data to decision making center. For the future application in the field, this study tested the packet loss rate between infrastructure node and gateway. The result shows that the packet loss rate is less than 0.6 %. The vibration frequency can be calculated accurately. In addition, the energy consumption in the field is also estimated.

Acknowledgements

The authors would like to appreciate the research support from the Ministry of Science and Technology in the Republic of China with the project no. NSC 101-2622-B-451-001-CC3.

This paper is a revised and expanded version of a paper entitled [The Development of Vibration Frequency Measurement Equipment for Bridge Pier] presented at [The 3rd International Conference on Next Generation Computer and Information Technology, October 24-26, 2014 at Hochimin, Vietnam]

References

[1] A. Zarafshan, I. Amirhossein and A. Farhad, "Vibration-Based Method and Sensor for Monitoring of Bridge Scour. Journal of Bridge Engineering, vol. 17, no. 6, **(2012),** pp. 829—838.

[2] E. V. Richardson and S. R. Davis, "Evaluating Scour at Bridges, 4th Edition, HEC-18", Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. **(2001).**

[3] B. W. Melville and S. E. Coleman, "Bridge scour. Water Resources Publications: Highlands Ranch", Colorado, **(2000).**

[4] C. P. Tsai and C. Lin, "Field Investigation and Analysis for the Causes of Bridge Failure during Typhoon Morakot", Institute of Transportation, Taiwan, **(2010)** (in Chinese).

[5] M. Lueker, J. Marr, C. Ellis, V. Winsted, and S. R. Akula, "Bridge Scour Monitoring Technologies: Development of Evaluation and Selection Protocols for Application on River Bridges in Minnesota", Minnesota Department of Transportation **(2010).**

[6] Y. M. Hong, J. R. Zeng, Y. C. Kan and H. C. Lin, "The Development of Vibration Frequency Measurement Equipment for Bridge Pier", Advanced Science and Technology Letters, vol. 63 (NCGIT 2014), **(2014),** pp. 36—40.

[7] Y.-B. Lin, J.-S. Lai, K.-C. Chang, W.-Y. Chang, F.-Z. Lee, and Y.-C. Tan, "Using MEMS Sensors in The Bridge Scour Monitoring System", Journal of the Chinese Institute of Engineers, vol. 33, no. 1, **(2010),** pp. 25—35.

[8] Y.-C. Kan, C.-C. Lin, W.-P. Sung, H.-C. Lin, and Y.-M. Hong, "Wireless Sensor Network Enabled Servo Velocity Sensors for Bridge Vibration. Disaster Advances", vol. 6, no. S4, **(2013),** pp. 395—402.

[9] K. Mitra, D. Bhattacharyya, and T. Kim, "Urban Computing and Information Management System Using Mobile Phones in Wireless Sensor Network, International Journal of Control and Automation, vol. 3, no. 1, **(2010),** pp. 17-25.

[10] Y.-M. Hong, H.-C. Lin, and Y.-C. Kan, "Using Wireless Sensor Network on Real-Time Remote Monitoring of the Load Cell for Landslide", Sensor Letters, vol. 9, **(2011),** pp. 1911-1915.

[11] Y.-M. Hong, H.-T. Lyu, W.-P. Sung, Y.-C. Kan, and H.-C. Lin, "Using Unified Modeling Language on the Development of real-time remote monitoring system for hillsope", Disaster Advances, vol. 5, no. 4, **(2012),** pp. 26-41.

Authors

Yao-Ming Hong, he received the B.S. and M.S. degrees in the Department of Soil and Water Conservation and the Ph.D. degree in the Department of Civil Engineering from National Chung-Hsing University, Taichung, Taiwan, R.O.C., in 1988, 1990, and 2002, respectively. He was a Senior Engineer at Moh and Associates, Inc. from 1992 to 1998. He was an Assistant Professor with MingDao University, Changhua, Taiwan, R.O.C., in the Department of Computer and Information Science from 2002 to 2007 and in the Department of Design for Sustainable Environment from 2007 to 2010. From 2010 to present, He was an Associate professor in the Department of Landscape Architecture and Environmental Planning. He is interested in hydraulic engineering, groundwater forecasting, and real-time remote monitoring systems using wireless sensor networks.

Jian-Rong Zeng, is a university student in the Department of Landscape Architecture and Environmental Planning from 2010 to present. In 2011, He joined the sustainable environment laboratory leaded by Yao-Ming Hong. He is interested in local scour of bridge pier, hydraulic engineering, real-time remote monitoring systems using wireless sensor networks.

Yao-Chiang Kan, he received the B.S. degree in physics from the National Cheng-Kung University in 1988 and the M.S. and Ph.D. degrees in electrical engineering from Michigan State University, East Lansing, in 1995 and 2000, respectively. From 1996 to 2001, he worked for Vertex Computer, Lansing, MI; Optimal CAD/CAM, Novi, MI, and VerbalTek, Santa Clara, CA. In 2001, he joined the Department of Information Engineering, Ming Dao University, Taiwan, R.O.C. In 2005, he transferred to the Department of Information and Telecommunications Engineering, Ming Chuan University, Taiwan, R.O.C. Since 2007, he has been an Assistant Professor of communications engineering with Yuan Ze University, Taiwan, R.O.C. His research interests include computational electromagnetics and wireless sensor networks.

Hsueh-Chun Lin, received the B.S. and M.S. degrees in Civil Engineering from National Central University, Chungli, Taiwan, in 1989 and 1993, respectively, and the Ph.D. degree of Civil and Environmental Engineering from UCLA in 1998. He worked for Telestar Corp. at Ontario in CA from 1999 to 2002. He was an Assistant Professor in the Computer and Information Science Department of Ming Dao University, Changhua, Taiwan from 2003 to 2006 and in the Department of Health Risk Management of the Public Health School, China Medical University, Taichung, Taiwan from 2006 to present. He is interested in structural mechanics, information technology and database system, clinical decision support system, ubiquitous healthcare network and environmental monitoring system on wireless sensor network.