Bridge Local Scour Monitoring System Using MEMS Sensor Zigbee Network

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ABSTRACT

Wireless MEMS sensors network has been widely used in many fields. In this paper the MEMS pressure sensor is integrated on a sensor board with Zigbee sensor network for real-time local bridge scour depth monitoring during a flood. The wireless MEMS pressure sensor scour monitoring system has been developed and tested in the laboratory. Local scour is one of the major factors for bridge failure. Scour failures tend to occur suddenly and without prior warning or sign of distress to the structure. Bridges subject to periods of flood/high flow require monitoring during those times in order to protect the traveling public. This wireless MEMS sensors scour-monitoring system can measure both the processes of scouring/deposition and the variations of water level. Several experimental runs have been conducted in the flume to demonstrate the applicability of the MEMS sensors network system. The experimental results indicate that the real-time monitoring system has the potential for further applications in the field.

Keywords: Zigbee, MEMS, wireless sensor network, bridge, scour

1 INTRODUCTION

It is well known that scour is one of the major causes for bridge failure[1-4]. When scouring occurs, the bed materials around the pier footing can be eroded, leaving the infrastructure such as bridge piers and abutments in an unsafe condition and in danger of collapse with the distinct possibility for loss of life. More than 1000 bridges have collapsed over the past 30 years in the U.S.A., with 60% of the failures due to scour[1]. This serious problem also happens in many East-Asian countries such as Taiwan, Japan, Korea…etc., owing to the fact that these areas are subject to several typhoon and flood events each year during the summer and fall seasons. Scour failure tends to occur suddenly and without prior warning or sign of distress to the structures. The nature of the failure is usually defined as the complete collapse of an entire section of a bridge. There were 68 bridges damaged due to scour damage in Taiwan, based on the survey from 1996 to 2001[5]. Scouring at a bridge pier in the river can be caused by general scour, contraction scour or local scour. Among them, local scour is the most critical and generally caused by the interference of the structures with river flow, and it is characterized by the formation of the scour hole at bridge piers or abutments. A great deal of time, money and efforts have been dedicated to the development and evaluation of scour detection and instrumentation in order to obtain more accurate measurements. However, it is not easy to measure or monitor the depth variations of scouring at piers, especially in a flood.

Therefore, the local scour depth monitoring system faces the challenge of developing a real-time, reliable and robust system, which can be installed in a river bed near the bridge pier or abutment. Moreover, it is well known that the established scour formula for estimating the maximum scour depth relates to the characteristics, including the flow depth, velocity and sediment size. In practice, the limitations of these scour formula should be addressed before one can apply them adequately. The recognition of any possible aggradation and degradation of the river-bed level in response to a channel disturbance is important for the prediction of channel bed variations. Besides, the scour process around the pier or abutment is essentially complex due to the three-dimensional flow patterns interacting with sediments. However, most of the data obtained to develop the scour formula are collected from the laboratory instead of from the field. Thus, it is necessary to develop a real-time system for monitoring and measuring the scour depth in the field.

There is growing interest in wireless sensor networks (WSN) in civil engineering and industrial applications. However, many challenges still lie in the way of improving the capabilities of wireless sensors. WSN monitoring has emerged in recent years as a promising technology that will greatly impact the field of structural health monitoring. Smart, wirelessly networked sensors can collect and process a vast amount of data, from monitoring and control of structural damage, air quality, traffic conditions, to weather conditions and tidal flows. In the present study, wireless MEMS sensors Zigbee network scour monitoring system is developed and utilized to the real-time measurement in the process of the local scour. Applying the wireless MEMS sensors Zigbee network systems, the laboratory data of the water level, scour depth and deposition height are collected and analyzed herein.

2 MEMS PRESSURE SENSOR

Over the past two decade, the micro electro mechanical systems (MEMS) sensor industry has continuously made progress. MEMS devices have already being used in a number of commercial applications, including projection displays, and the measurement of pressure and acceleration. New applications are emerging as the existing technology which is applied to the miniaturization and integration of conventional devices.

Today, MEMS sensors offer very high accuracy at very low cost and provide an interface between the mechanical world and the electrical system. In this paper, MEMS pressure sensor was fabricated using a 4 inch double side polished P(100) wafer. The sensor die consists of a thin Si diaphragm fabricated by bulk micromachining. Prior to the micromachining, piezoresistors are patterned across the edges of the diaphragm region using standard IC processing techniques. After etching of the substrate to create the diaphragm, the sensor die is bonded to a Pyrex glass substrate to realize a sealed vacuum cavity underneath the diaphragm.

Conventionally, the die is mounted on a package such that the top side of the diaphragm is exposed to the environment through a port. Herein, the house of the pressure sensor die was filled with silicon oil. To preventing corrosion or conduction, an indirect stainless foil bonding approach with different thickness is applied to weld onto the bottom of the sensor house for adapting in the fluid field. This pressure sensor as shown in Fig. 1 is then ready to integrate into the Zigbee sensor board for test.

3 ZIGBEE

The wireless monitoring system with micro-electro-mechanical system (MEMS) sensors could reduce system cost and time consume dramatically. A wireless monitoring system should provide relevant data from the observed structure without the requirement to inspect. So the data has to be transmitted in a sufficient way to the users. An on-site central unit for data collection and storage in a database and further to analyze the data from sensor node is needed. The central unit also should allow a calibration and a wireless reprogramming of the sensor nodes to keep the whole system flexible.

Moreover, in a situation when the network goes down, for example due to power failure, the application should be designed to take care of the recovery of the network to its previous state and continue with data transmission without any errors. Choosing the right network topology that best suits the application is an important decision. When data reliability is crucial, mesh architectures provide the best shield against signal degradation and loss of data.

Zigbee is a wireless standard based on 802.15.4 that was developed by the Zigbee Alliance (an organization of semiconductor manufacturers, technology providers, and OEM's), Zigbee incorporates the network, security and application layers that reside on top of the IEEE 802.15.4 WPAN standard.

Zigbee supports star, mesh, and cluster-tree network topologies as shown in Fig 2. It is important to ensure applications using robust routing algorithm to obtain the best possible route for data transmission from one node to another and remember them.

4 TEST AND RESULTS

Fluid pressure can be measured directly by the pressure sensor. Absolute pressure was measured using MEMS pressure sensors under atmospheric pressure. The MEMS pressure sensor Zigbee network local scour monitoring system is developed in the present study. As shown in Fig. 3, these two series aligned pressure sensors, namely s1 and s2, are individually mounted in 10 cm interval on the pier placed in the flume. The s1 is installed at the 10 cm height near the lower end of the pier while s2 is installed at the upper site. These sensors are connected directly to the Zigbee sensor board to wireless send all the real-time measured data to the coordinator (notebook) for further analysis.

The experiments were conducted in a 12 m-long, 1 m-wide and 1.2 m-deep flume with glass sidewalls at the Hydrotech Research Institute of National Taiwan University, Taipei, Taiwan. The pier was fastened in the middle of the flume. The prescribed discharge and its corresponding depth for each experimental case were controlled by adjusting the inlet valve and tailgate. To simulate scouring/deposition of the river bed, a dune-like bed formation is assumed in the experimental setup.

Items measured include the calibration of the sensors under static pressure, the response of the sensors under current, upraised water flow measurement, and scour progress. When the rising water surface reaches the sensors, pressure will be detected directly.

As presented in Fig. 4 the s1 sensor was continuously impacted under a 2m/sec spouted flow using a water pipe to test the performance of the sensor. Due to the unsteadiness of the jet flow in the water pipe, oscillation pressures in terms of volts were observed. These oscillation volts/signals under a 2m/sec flow velocity demonstrated the performance of the designed MEMS pressure sensor can be used in a swift/storm flow under a flood. As shown in Fig. 5, the static pressure is measured under steady state conditions as the flow tapping into the sensors. The calibration factors between the water depths and the pressures are obtained.

The rising flood with strong current not only attacked bridge but also caused disaster when it overflowed the riverbank during a torrential flood. Real-time measurement of the rising water level is also important. To measure the water level during the upraised flow, results of the flow pressures against time are shown in Fig. 6. The s1 sensor was impacted by the elevated flow firstly at about 30 second while the s2 was at 65 second. Due to the static pressure in the flume, the pressures of the s1 were steeper than those of s2. About 0.14 psi static pressure difference between these two sensors was 10 cm in vertical. As mentioned, a dune-like bed formation is assumed in the experiment to simulate scouring progress of the river bed. Scouring progress is shown in the Fig. 7 from the responded sensors. Both sensors are submerged in the dune-like bed with 50 cm deep water. As the water flowing toward the pier, scouring results from the flow shear near the bottom will be detected by the pressure sensors and that revealed the scour depth as these sensors emerged from the riverbed.

The experimental results indicate that the real-time monitoring system has the potential for further applications in the field. It is evident that test results from the MEMS pressure sensor using Zigbee sensor network is much convenient and innovative than those from conventional wired approaches. Moreover, this monitoring system not only useful for scouring safety of a bridge, but it also benefited to integrate the accelerometers onto the single sensor board for bridge health diagnosis during earthquake attacked. Additional accelerometers with pressure sensor Zigbee network board can be directly attached onto the pier/abutment. The resistant performance characters under torrential flood or earthquake attacked of a pier and abutment is then monitored at real-time and at anytime as these events happened. Definitely, wireless sensor network using Zigbee protocol which provides real-time information will help engineers and bridge governor for bridge maintenance and operation under natural disasters.

5 SUMMARY

Scour is one of the major causes for bridge failure. Scour failures tend to occur suddenly and without prior warning or sign of distress to the structure. Bridges subject to periods of flood/high flow require monitoring during those times in order to protect the traveling public.

MEMS pressure sensor scour monitoring system using Zigbee sensor network has been developed and tested in this study. Several experimental runs of measuring water level and scour depth using this system have been conducted and demonstrated in the laboratory. The experimental results indicate that the real-time monitoring system has the potential for further applications in the field.

It is evident that results from the MEMS pressure sensor using Zigbee sensor network is much convenient and innovated for real-time scour monitoring. Moreover, this monitoring system not only useful for scouring safety of a bridge, but also it benefited to integrate the accelerometers onto the single sensor board for bridge health diagnosis during earthquake attacked. The resistant performance characters under torrential flood or earthquake attacked of a pier and abutment is then monitored at real-time bases. Definitely, wireless sensor network using Zigbee protocol providing real-time information will help engineers and bridge governor for bridge maintenance and operation under natural disasters.

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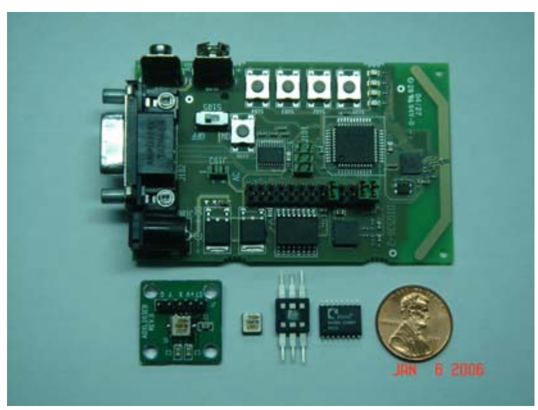

Fig. 1 MEMS Zigbee network sensor board

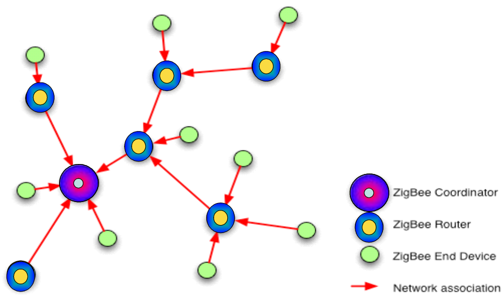

Fig. 2 Zigbee network

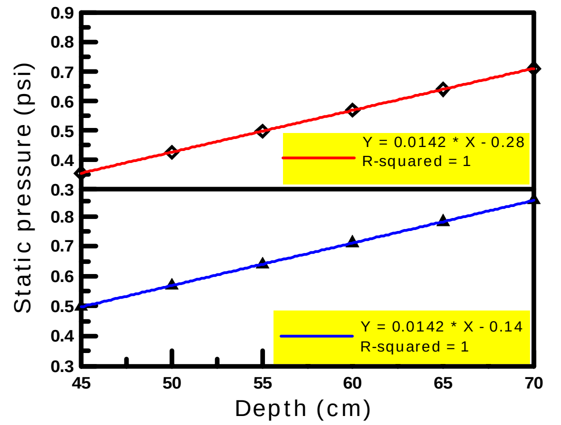

Fig. 5 Calibrations of the MEMS pressure sensors under still water condition

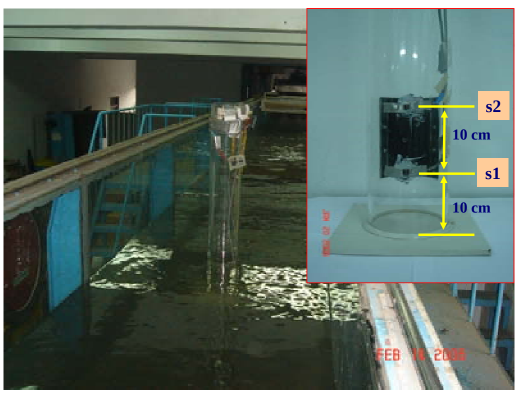

Fig. 3 MEMS pressure sensor Zigbee network scour monitoring system setup in the laboratory

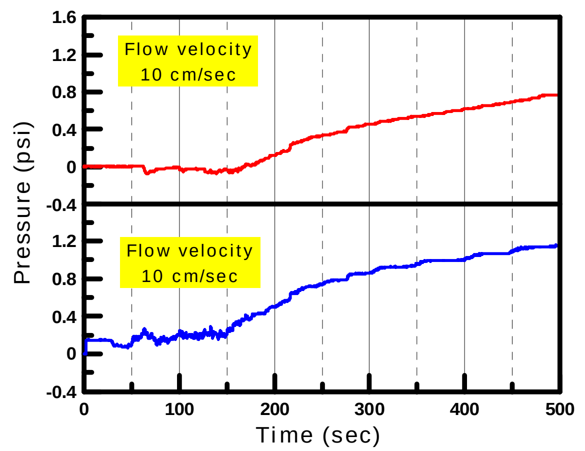

Fig. 6 Progress of pressure sensor during upraised flow

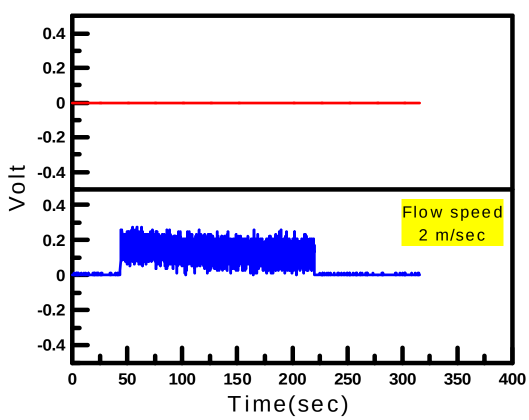

Fig. 4 Calibration of pressure sensors under static pressure

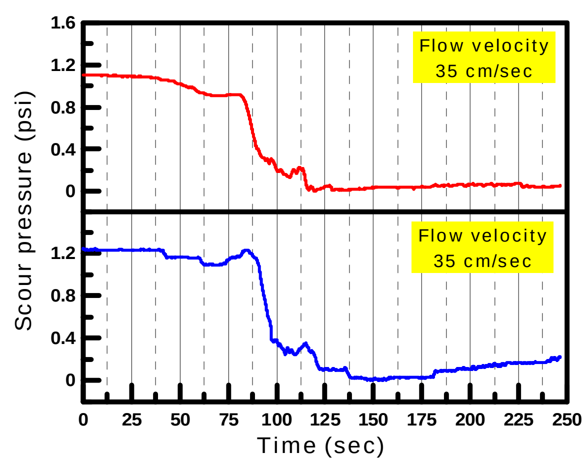

Fig. 7 Progresses of pressure sensor during scour