DEVELOPMENT OF AN INNOVATIVE BRIDGE MONITORING SYSTEM FOR MULTI DISASTERS

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ABSTRACT: Transportation infrastructure plays an important role in national development. With such unique geographic environment, bridges become the majority of transportation infrastructure and building the bridges is regarded as one of the most important public construction projects in Taiwan. However, Taiwan is also known as its natural disasters such as earthquakes and typhoons, which will cause severe damage or even destroy the bridges. For example, Houfeng Bridge was torn down by the flood in 2008. In 2009, another bridge – Shuangyuan Bridge – was also destroyed by debris flow. Several lives were lost in these two accidents. Therefore, it is in doubt that traditional Bridge Monitoring System (BMS) could provide sufficient real-time information to competent authorities. In order to mitigate the damage or even prevent any loss of property or life from the disasters, an innovative BMS based on Wireless System Network (WSN) technology is studied and applied for field applications. For the purpose of providing real-time information to competent authorities, an information management platform will also be developed to work with the monitoring system.

Keywords: *Bridge Monitoring System (BMS), Wireless Sensor Network (WSN)*

1. Introduction

Taiwan is an island consisting of hundreds of rapid rivers. Based on the unique geographical environment, bridges are highly required and finally become the majority of public transportation (construction) projects. Since Taiwan is located on the boundary of Eurasian plate and Philippine tectonic plates, earthquake frequently happen. No doubly, it is important to prevent aging bridges, which are easily and highly- possibly damaged or even destroyed by earthquakes, form the deadly earthquakes. Table 1 show the number of earthquakes happened in the past 10 years.

Table 1 Number of Earthquakes Happened in the Past 10 Years（Central Weather Bureau）

Year	2001	2002	2003	2004	2005
Number	334	425	347	262	557
Year	2006	2007	2008	2009	2010
Number	405	426	476	752	614

Subtropical climate also has significant influence on bridge structures. The typhoons, which are resulted from tropical depression and happen in late summer, will seriously damage aging bridges. In 2009, Typhoon Morakot (International designation: 0908, JTWC designation: 09W, PAGASA name: Kiko) attacked Taiwan and was later known as the most deadly typhoon in recorded history. Morakot brought the highly-humid southwest air flow, which resulted in consecutive 48-hour heavy rain in southern Taiwan. Table 2 shows the cumulative precipitation of main rivers basin in southern Taiwan. In addition, serious landslide from hillside located in the upstream of the river was triggered by the heavy precipitation. The fast-moving, liquefied landslide (also known as Debris Flow) caused severe structural damage to 196 bridges; fifty of them were destroyed. More unfortunately, numbers of people fell into the river accidentally in the moment when Shuangyuan Bridge collapsed due to the flood.

Table 2 Top 5 Cumulative Precipitation in Single River Basin by Morakot (8/5 - 8/10, 2009)

Location	Cumulative Precipitation	River Basin
Alishan	3,060mm	Zengwun Ri ver
Mt. Weiliao	2,910mm	Kaopig River
Fenqihu	2,863mm	Bajhang Riv er
Mt. Yuyo u	2,823mm	Kaopig River
Sinan	2,747mm	Kaopig River

Except for natural disasters such as earthquakes and typhoons, over-exploitation of natural sand and gravel resources and structure corrosion/erosion are reasons which will cause bridge destruction as well. In the past, regular maintenance, bridge safety assessment or checking the water level after natural disaster to determine whether the bridge should be closed were used to prevent accidents resulted from damaged bridges. However, those traditional methods are not able to handle the damage caused by unpredictable weather anymore. Therefore, it is highly required and important to develop a new type "Innovative Bridge Monitoring System," which can instantly react to the damage caused by different or even composite natural disasters, record and report the data to the authorities and then timely warning the public.

2. Innovative bridge monitoring system

In order to collect the data as precise as possible, the instruments used in the Bridge Monitoring System were extremely expensive. That is, it is almost impossible to widely deploy the instruments and the detection area was limited. In addition, we have to use great amount electricity since we cannot have numbers of instruments to perform different functions. The electricity supply will be a severe problem. Moreover, since we are doing observation and monitoring in a long-time period, back-up electricity supply would be another serious problem if any natural disasters happen. Every instrument was vulnerable. If any of the instruments lost the electricity support or even destroyed, the Bridge Monitoring System (BMS) would not able to function and will lost the ability of instant monitoring and preventing possible damage.

In order to solve the problem, this research utilize Wireless System Network (WSN, Figure 1), a system consisting of a collective of networked sensor nodes designed to communicate to each other via wireless, to develop an innovative BMS. WSN has following characteristics: 1) Integrating sensors (such as accelerometers, temperature sensor, humidity sensor and inclinometers) micro processor, and communication capabilities. 2) Low-cost and power-efficient, which means WSN sensors can be widely deployed to the bridge to increase the detective area. 3) WSN sensor is much smaller than traditional instrument. 4) WSN sensor was designed to "Sense environment, acquire information, and handle message." That is, WSN sensor can collect data from the environment directly, simply analyze data the sensors receive and then send all information to receiver. The researchers can do analysis based on the information that the receiver get and make instant but correct reaction to the safety issues of the bridges. ZigBee is the standard Communication Protocol to be used in this research. The most advantage is that there is no "designated direction" between sensors–that is, a sensor can be used not only as a data sender but also as a data receiver. Since ZigBee is sending data via radio wave and there are no obstacles between each sensor when the monitoring system is operated, the quality of data transmission would be assured.

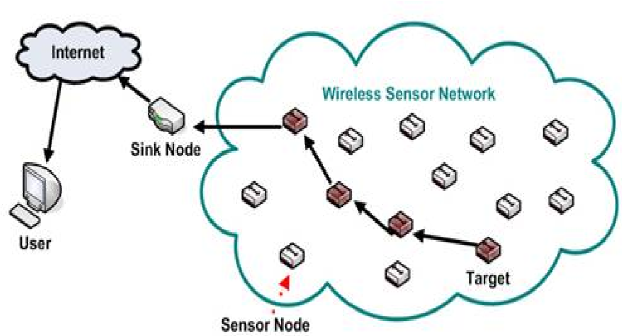

Fig.1 Basic Characteristics of WSN

3. Experimental field applications

Exposed pile foundation (, as Figure 2) has negative impact on the bridge structure and is big threat to the safety. Unfortunately, it is common in Southern Taiwan. Therefore, it is necessary to install the BMS and then record and carefully monitor the structural vibration and scour depth of foundations. In this study, the selected structure and field application of bridges in southern Taiwan will be examined, the information will be showed in Table 3. The aim of this research is to provide a bridge instant scour monitoring system. Bridge #3 is one of the exposed foundation bridges caused by scouring; moreover, Bridge #3 is the oldest one of the four and is still in danger due to serious scouring even though the government paid great effort on the replacement. Thus, it is exactly match the scope of this research.

Fig.2 Exposed Pile Foundations

Bridge No./ Name	Bridge1	Bridge2	Bridge3	Bridge4
Construction year	1978	2003	1978	2002
No. of Span	30 spans	68 spans	67 spans	37 spans
Length	1,050M	2850M	2344M	1620M
Width of bridge deck	15.22M	26.73~15.15M	15.22×2M	15.15M
Height of bridge piers	9.42M~11.79M	39.64M	9.45M	13.57M
Material of foundation piles	Concrete	Concrete	Concrete	Concrete
Shape of foundation piles	Circular	Circular	Circular	Circular
Diameter of circular foundation piles	1.2M	1.5M	1.00m	1.5M
Length of foundation piles	18M	20M	25m	24M

Table 3 Basic Information for the Chosen Brides

By developing WSN, it becomes possible to integrate multi-sensors, such as accelerometer, inclinometer, strain gage, settlement-extensimeter and GPS, into a single network. It is more efficient for wide-ranged detection from different location. GPS can help sensors correcting their location to each other and then know the distance to other sensors. Collecting data will be sent to coordinator via WSN and then transmit to the server we settled for this research. Through the Bridge Monitoring Platform we settled, the actual structural and operating conditions can be sent to the managerial department and personnel instantly. If any of the bridges are not able to be operated under overwhelmed disasters, the competent authorities can release the warming to potential road users and take action against the damage immediately to ensure the safety for the road users. The deployment of bridge monitoring system is shown in Figure 3.

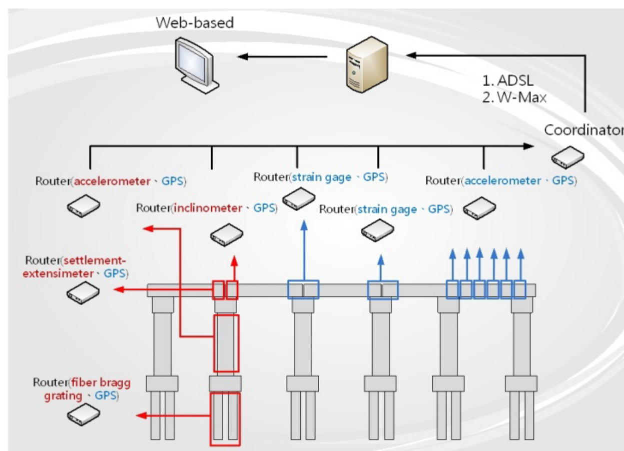

Fig.3 Deployment of bridge monitoring system

The functions of the Bridge Monitoring Platform (BMP) can be divided into several different categories:

1. Real-time Bridge Monitoring: Displaying the physical quantities measured and recorded by each instrument as well as the meaning of the numbers. The purpose of this function is sending warning signal out when the bridges are in danger of destruction. Thus, the competent authorities can take action, such as closing the bridge or evacuating the residents, against the disasters.

2. Historical Data Searching Page: Providing the basic information of bridges for inquiry. As shown in Figure 4, the historical data searching page includes recodes of

regular maintenance, inspection, emergency repair and regional disaster history.

Fig.4 historical data searching page

4. Summary and Remarks

There are still some problems need to be solved. First of all, although WSN sensors are power-efficient, the back-up power supply for emergency usage was still in question. If any of the natural disasters we mentioned in previous paragraph cause long-time power disconnection, how long can the back-up power system operate and how much power the back-up power system and provide? Another problem is that WSN sensor is still damaged in chances, if the research team needs to regularly replace the sensor in a short period of time, the system is regarded as inefficiency. All of these problems are still need to be solved in further studies and ongoing researches.

In this study, WSN was applied to BMS. As the system develops, all information can be sent to the competent authorities or even the public to achieve our goal – early warning-signal can be sent out before disasters really cause any damage to or destroy the public infrastructures. As the technology becomes more mature, the system can be integrated with smart phones or other portable (or mobile) devices. The public can receive the information of coming disasters through the website and take reaction immediately to prevent any potential property damage or loss of life. That is, the government can minimize the damage carried by the disasters.

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