DEVELOPING BRIDGE MONITOR PLATFORM USING GPS AND COMMUNICATION TECHNOLOGY

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ABSTRACT: In order to maintain security of the bridge and prevent life and property losses caused by earthquakes, typhoons, erosion and other disasters, it is worthwhile to explore the installation of monitoring and management system for bridges. However, in the current bridge management process, most of the discussion is divided into two parts: superstructure and substructure. In this research, the Wireless Sensor Network based accelerometer and inclinometer, as well as GPS correction, are installed on the superstructure to obtain complete bridge monitoring information. In the substructure of the bridge, scour monitoring equipment, two-way accelerometer, settlement terms and inclinometer are installed. All monitoring information is integrated to develop a comprehensive assessment of indicators that effectively monitor bridge safety. This study uses in-depth interviews and multivariate analysis to establish monitoring indicators. Relationships between the monitoring indicators and their weights, as well as monitoring standards, are developed through the Analytic Network Process (ANP) and the bridge model′s force endurance history analysis. Warning lights show the different levels of potential disaster so that bridge maintenance may be carried out according to the bridge′s status for timely repair and rehabilitation. The research focuses on the historical behavior database, using monitoring indicators to prompt risk management and control of existing bridges. A Web-based integrated bridge disaster prevention and management platform distributes all bridge monitoring information for users, and may serve as a precaution for bridge disasters.

Keywords: *Bridge Disaster Prevention and Management, Real-time Monitoring, Wireless Sensor Network, Disaster Warning*

1. INTRODUCTION

The main function of bridge monitoring platform is to use automated sensor system to continuously measure the depth of erosion, but nowadays most erosion detection equipment cannot achieve real-time monitoring. If the bridges contain potential dangers due to accumulated erosion over the years, a severe flood may cause the bridge to collapse and threaten public safety. Taiwan is located at the intersection of plates and contains many high mountains and swift rivers. Densely populated, the over twenty thousand bridges in Taiwan play an important role. Damaged bridges cause not only life losses and disruption of traffic but also often result in economic damage; Kao-Ping Bridge and Hou-Feng Bridge are evident examples. As a result, the development of integrated bridge monitoring platforms is a very important topic for discussion.

Bridge monitoring is an ongoing work that requires continuous real-time controlling, thus the bridge monitoring platform must monitor all important nodes on the bridge using 30 HZ frequency at all times. This manner of monitoring produces a large amount of data, bringing about the challenge of filtering correct information and sending out timely warning signals. Other problems faced in the development of bridge monitoring platforms include how to use economical and accurate devices, how to ensure the stable supply of bridge electricity, and how to prevent the sensor from damage under extreme weather.

2. LITERATURE REVIEW

After careful literature review, current bridge monitoring systems can be divided into the following types:

Table 1 Evaluation Table of Monitoring Devices

Instrument \ Function	Real Time	Silt up	Durability	Data process	Power module	Cost
Bridge Site Brick	No	No	Well	Simple	No	Low
Wireless Micro-signal Device	Yes	No	Well	Simple	Need	Low
Sonar Instrument	Yes	No	Bad	Hard	Need	High
Ground Penetrating Radar	No	No	Bad	Hard	Need	High
TDR	Yes	Yes	Well	Simple	Need	High
Magnetic Sliding Collar	Yes	No	Bad	Simple	No	Low
Fiber Bragg Grating System	Yes	Yes	Well	Simple	Need	High
Underwater Camera	Yes	Yes	Bad	Simple	Need	Low
Heavy Hammer Erosion Detection Meter	No	No	Bad	Simple	No	Low
Temperature-type Erosion Detection Meter	Yes	Yes	Well	Simple	Need	Low

*The items highlighted in gray denotes meeting function requirements

Burying Bridge Site Brick, Wireless Micro-signal Device, Sonar and Ground Penetrating Radar, Time Domain Reflectometry (TDR), Magnetic sliding collar, Fiber bragg grating scour monitoring system, Heavy hammer scour monitoring equipment, Temperature scour monitoring equipment, etc. These equipment are analyzed in Table 1 according to their characteristics regarding real time, silt up, durability, data process, power module, and cost. Since timely monitoring is required and the high-speed high-way installation sites reject all complicated devices, the performance of real time, durability, and cost are the most important considerations in choosing monitoring systems. Only Wireless Micro-signal Device and Temperature scour monitoring equipment meet the needs of all three requirements. Yet the Temperature scour monitoring equipment measures water height using temperature, which is not only inaccurate but unsuitable under extreme weather, thus the Wireless Micro-signal Device is the chosen method for monitoring.

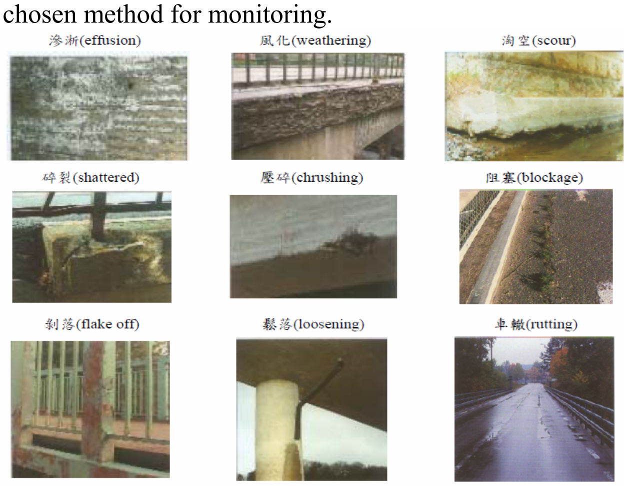

Fig. 1 Types of Spontaneous damage

Table 2 Causes of Spontaneous damage

Types	Causes
Cracking	The damage impact of cracks in concrete depends on whether its size grows with time. The cracks in concrete are strip-shaped and may expand to part or whole of the concrete structure.
Scaling	Scaling is due to the peeling of cement mortar at the concrete surface. Peeling usually occurs at the concrete surface layer with poor quality, due to bad treatment of the surface.
Rebar Rusting	Rebar rusting is due to electrochemical degradation. Rusting occurs when oxygen and moisture are present during the time the steel's protective film is destroyed.
Crazing	Crazing are tiny cracks upon concrete surface with irregular shapes. These types of cracks do not harm the safety of the concrete structure and won't immediately deteriorate the concrete.
Spalling	Spalling is the phenomenon of concrete peeling off in slices, the main cause being corrosion or the concrete being pulled by a force larger than allowed value.
Popout	Popout is due to the coarse aggregate particles at the surface of concrete. These particles readily absorb water. Under freezing conditions the particles will swell and break, making the weaker cement mortar at the surface burst.
Popout	Popout is due to the coarse aggregate particles at the surface of concrete. These particles readily absorb water. Under freezing conditions the particles will swell and break, making the weaker cement mortar at the surface burst.
Pitting	The scope of cement pitting is a net-like circle or oval, which will peel off, parallel or tilted from the cement surface, sometimes even the steel will be exposed.
Honeycombing	Honeycombing is due to the failure of filling in the spaces within aggregates during construction.
Efflorescence	Efflorescence if the decomposition of the surface of concrete structures. Weathering and seepage are among the most common phenomena of surface decomposition. Weathering is the decomposition of salt and usually appears white due to the calcium hydroxide seeping to the surface.
Delamination	Delamination is the phenomenon of cracks not on the concrete surface but hidden a distance under the surface. These kinds of hidden cracks are fairly long and wide, and thus when tapped with steel, the sound coming from it is different from denser concrete.
Cavitation	Similar to honeycombs in appearance, cavitations often occur several months or even years after pouring. When water flows

The Wireless Sensor Network (WSN) developed by National Taiwan University is the chosen monitoring platform. As for the inductor, the accelerometer with lower precision is chosen.

Bridge damage can be divided into spontaneous damage and non-spontaneous damage. Spontaneous damage include effusion, weathering, scour, shattered, crushing, blockage, flake off, loosening, rutting, etc. (Fig. 1) The damage causes are described in Table2.

Non-spontaneous damage is usually caused by flood erosion on bridges. Related cases are listed in Fig. 2. From related literatures, erosion causes the worst damage out of all damage origins. This, this study focuses on erosion monitoring.

橋梁名稱	后豐大橋	橋梁名稱	雙園大橋	橋梁名稱	大洲大橋
所在鄉區	臺中縣后里鄉	所在鄉區	高雄縣林園鄉	所在鄉區	高雄縣旗山鎮
路線等級	臺 13 線	路線等級	臺 17 線	路線等級	高 92
竣工年月	87 年 2 月	竣工年月	70 年 10 月	竣工年月	85 年 6 月
橋梁總長	640 公尺	橋梁總長	2082.8 公尺	橋梁總長	160 公尺
總橋孔數	16 孔	總橋孔數	68 孔	總橋孔數	4 孔
最大跨距	40.3M	最大跨距	31M	最大跨距	40M
主梁材質	預力混凝土	主梁材質	預力混凝土	主梁材質	鋼筋混凝土
災損情形		災損情形		災損情形	
沖垮 P2 橋墩上游側兩支橋墩，造成 S2 及 S3 上游側落橋，下游側下陷傾斜。		P1 橋墩起至 P16 橋墩間計 459 公尺長橋面版及橋墩遭洪水沖毀。		橋梁沖毀。大州大橋沖毀，橋梁中斷。	
災損照片		災損照片		災損照片	
					

Fig. 2 Cases of Non-spontaneous damage

3. PROBLEM STATEMENT AND STRATEGIES

The topics discussed in this research can be divided into three parts: installation of monitoring device, processing of monitoring data, and planning of monitoring system, as shown in Fig. 3.

1. Installation of monitoring device,

(1) How to ensure the stable supply of bridge electricity: The monitoring platform on the bridge needs stable electricity in order to ensure the continuous flow of data transmission. The electrical devices include the sensors at each node, the electricity needed for wireless transmission, and the antenna (Fig. 4). To guarantee stable electricity, this research provides its own electricity distributor for monitoring.

(2) How to select economical sensors: As shown in Fig. 3, the different sensors that can be used in bridge monitors are listed. The causes of bridge damage consist mainly of vibration and erosion. Micro-vibration and accelerometer can both be used to monitor vibration in bridges, but due to economical concerns, the accelerometer, which provides less precise measurements, is chosen.

As for erosion, no suitable sensor has been found, thus an analysis on dynamic models is conducted to determine relationship between frequency and erosion. The frequency information measured by the accelerometer is then used to estimate the amount of erosion. This method allows using a low cost sensor to determine both vibration and erosion. Furthermore, to synchronize the monitoring data of the accelerometers at each node, a low precision GPS, which nevertheless has accurate timing function, is chosen for this task.

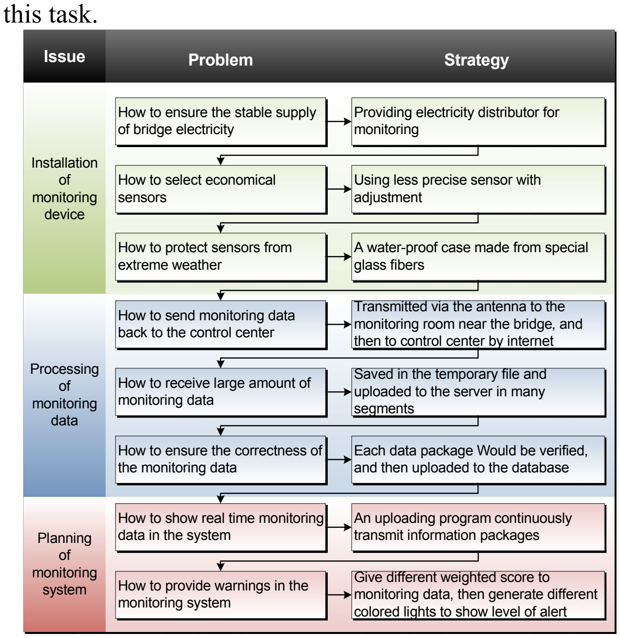

Fig. 3 Problem statement

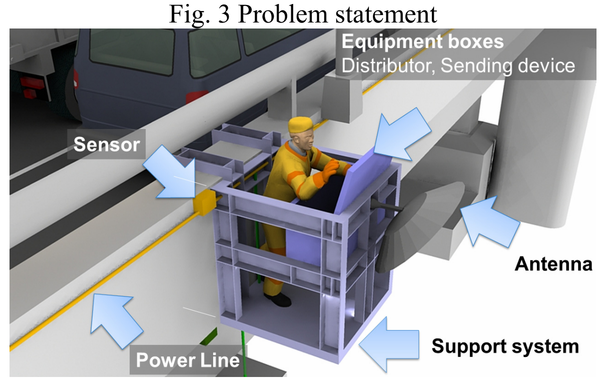

Fig. 4 Installation of monitoring device

Table 3 Table of different Sensors

Sensor	Model	Frequency	Accuracy	Limitation	Price (NTD)
GPS	Topcon GR-3 static	30min	3mm+.5ppm H 5mm+.5ppm V		600K
	Topcon GR-3 RTK	10sec	10mm+1ppm H 15mm+1ppm V	-20~50℃	600K
	Rarallax GPS receiver	20~30ms	15m without WAAS: 0.1m/s	18~78℃	2K
Micro-vibration	Tokyo Sokushin VSE-15D-1	0.1~70Hz	Velocity:10μkine Acceleration:10^{-5} Gal	+/-2000Gal -10~50℃	150K
Accelerometer	Analog ADXL 322	5.5kHz	1.34~2.68Gal	+/-2Gal -20~70℃	1K
	PCB Piezotronics 393B04	0.02~2000Hz	0.003Gal	+/-5Gal -18~80℃	40K
Inclinometer	FAS-A	30Hz	Pitch, Roll:±0.7°	360°	2K
Thermo-hygro meter	SHT1x	Temp.:5~30sec Humidity:4sec	Temp.: ±0.5° Humidity: ±3.5%RH	-40~123.8℃ 0~100℃	1K
LDV	Polytec PDV-100+	Analog:0.5~22kHz Digital:0~22kHz		0.2~30m ±5~40℃	870K
	OFV-505			Max distance>300m	2~3M
LIDAR	Trimble GS200	3mm@100m	1.4mm@5m~ 6.5mm@200m	2~350m	2.5M

(3) How to protect sensors from extreme weather: In extreme weather, heavy rain and strong wind are the most common causes of damage. A shown in Fig. 5, a water-proof case made from special glass fibers is used to protect the sensors. The cases consist of the main body and a protecting cover, 4 centimeters and 1.5 centimeters deep, respectively. The temperature resistance is 40°C~110°C, and may protect the sensors from damage due to extreme weather.

Fig. 5 Sensor protection case

2. Processing of monitoring data

(1) How to send monitoring data back to the control center: Each sensor sends its information to the coordinator via wireless transmission. The coordinator sends out monitoring data via RS232 to the format transformer and transforms the information package into RJ45 format. This package is then transmitted via the antenna to the wireless receiving device in the monitoring room near the bridge. The package is further transmitted through RJ45 to the switch and to the host computer in the monitoring room. The package is saved as several segments in the database of the control center by using the VB.net transmission program. Finally, the real-time monitoring data is shown on the monitor platform. This transmission process is shown in Fig. 6.

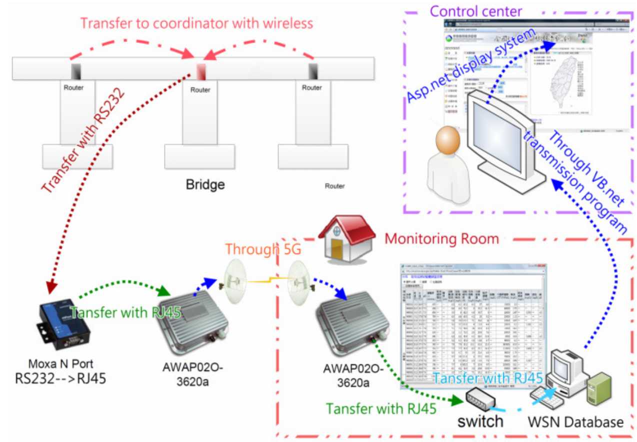

Fig. 6 The process of information transmission

(2) How to receive large amount of monitoring data: The monitoring device in this study uses 30 Hz frequency to transmit data. To avoid insufficient capacity while the sensor transmits data, the data is first compressed in the sensor. When the data is transmitted to the monitoring room, it is saved in the temporary file and uploaded to the server in the control center in many segments. This is to ensure the information will be completely received.

(3) How to ensure the correctness of the monitoring data:
To ensure the correctness of each monitoring data, each data package has been added an identification code at the head and at the end of the file. Before the monitoring data enters the monitoring room, each identification code would be verified with VB.net. Once the data is verified as correct, it will be cut into several segments and uploaded to the database (as shown in Fig. 7). Packages with error file heads or ends will be deleted.

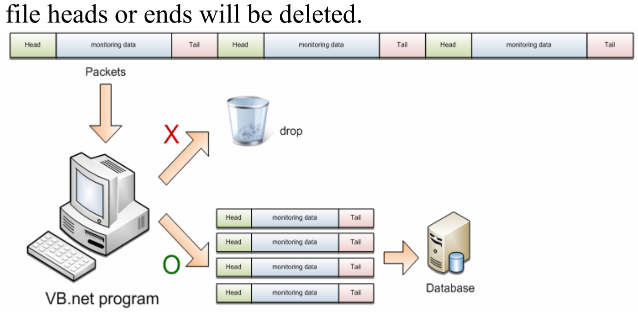

Fig. 7 Checking of monitoring data

3. Planning of monitoring system

(1) How to show real time monitoring data in the system: An uploading program written by VB.net has been developed in this study to continuously receive information packages. The monitoring data is uploaded to the database in the control center, and the monitor platform

reads from the same database simultaneously and shows the content via web-based ways, which is in real-time.

(2) How to provide warnings in the monitoring system: As shown in Fig. 8, a weighted score is given to the monitoring data according to the level of alert, and different colored lights stand for different danger situations.

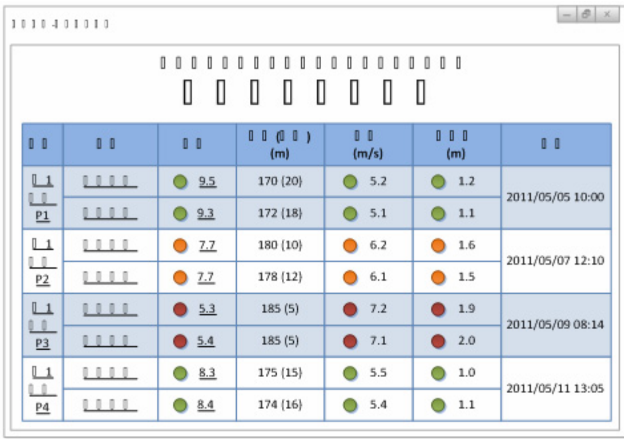

Fig. 8 monitor platform page

A red light denotes a warning, an orange light denotes caution, and green means the sensor is in safe status. If the user desires detailed information, they may do so by reading the corresponding information. The monitoring data's detailed information page shows the historical records of the sensor and provides suggestions to deal with the damage (see Fig. 9).

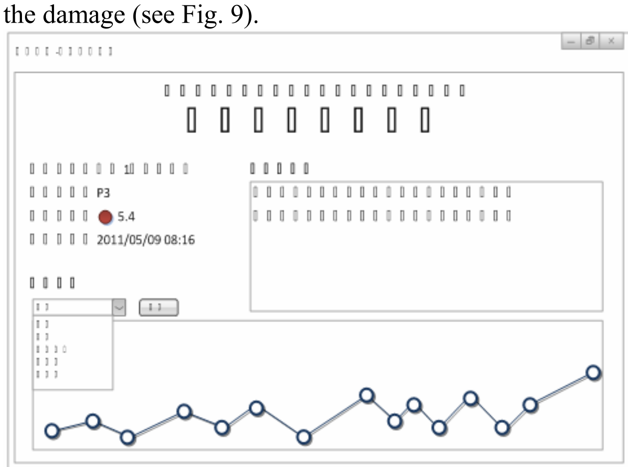

Fig. 9 Page of monitoring data detailed information

The manager can carry out emergency procedures by following the suggested steps. By clicking on the bridge's sensors, all the monitoring data can be read, providing users with visualized data (see Fig. 10).

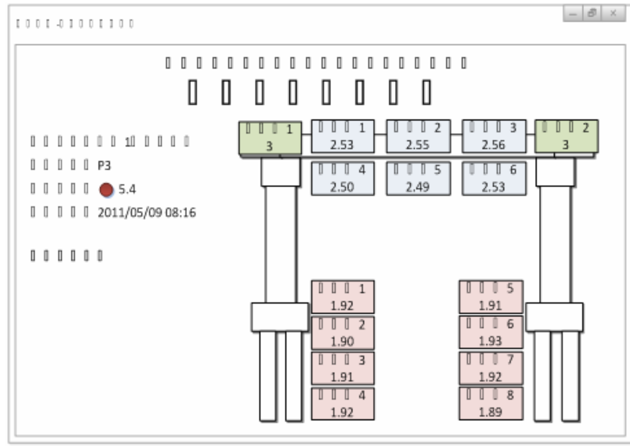

Fig. 1. Monitoring Data

4. DISCUSSION AND CONCLUSIONS

The research focuses on using historical behavior database and monitoring indicators to prompt risk management and control of existing bridges. A Web-based integrated bridge disaster prevention and management platform distributes all bridge monitoring information for users, and may serve as a precaution for bridge disasters.

The results of our study include:

1. The application of WSN and GPS in the monitoring of bridges, together with wireless transmission technology, to develop a real-time monitoring data transmission device, which can replace traditional single unit cable devices.

2. The development of monitoring information transmission programs. The beginning and ending of each file is used to determine the correctness of the monitoring information. The information is transmitted continuously to the managing center to realize monitoring.

3. The development of a bridge disaster prevention platform: different light signals are used to notify users of the damage status of the bridge as well as make suggestions to prolong the reaction time during disasters.

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