



Integrating Real-time Bridge Scouring Monitoring System with Mobile Location-Based Services

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Abstract: Typhoons and torrential rains not only erode river beds and coasts and damage river-crossing structures, but also affect the geomorphology and topography of rivers and coasts. Additionally, typhoons and torrential rains cause debris flows and flooding in metropolitan areas and threaten the safety of people's lives and properties. Disaster prevention and reduction of damage caused by typhoons and torrential rains have always been a crucial task of government agencies. Bridges in Taiwan are generally old and have insufficient shock resistance; some bridge foundations are also severely eroded and exposed. Because of global climate changes in recent years, rainfall has become comparatively heavy and rapid. Furthermore, the soil in mountain areas has softened because of factors such as earthquakes or human developments. Debris rushes down with rain every time a torrential rain strikes, significantly impacting the safety of bridges downstream. Although government bridge management units have made budget plans to progressively renovate dangerous old bridges, these bridges are still being used for traffic and transportation. These dangerous old bridges pose a serious threat to the safety of people when an earthquake, typhoon, or flood occurs. During typhoons and floods, increased water levels and changes of the scouring depths have dramatic effects on the safety of bridges. The bridge maintenance units currently use the water level and water flow conditions as references when determining whether to close a bridge; however, this is not a good permanent solution. A bridge scour monitoring and warning system that is stable, reliable, and operates normally under flood attacks is required for on-site installation and verification. In recent years, the applied technologies of smart phones have expanded beyond entertainment and communication. Mobile communications are used to transmit relevant information to bridge maintenance and management units and road users when a bridge is potentially damaged. The instant conveying of information allows the bridge management units to implement instant disaster rescue response measures and to notify road users to avoid the dangerous road sections, protecting people's lives and properties.

Keywords: Location Based Service; bridge scour monitoring and warning system; flooding; wireless sensor network

1. Introduction

The natural environment of Taiwan is beautiful; however, its geographic location is unique. Plum rain occurs between May and June, and typhoons are frequent during July and October every year. This unique

climate often brings torrential rain. Taiwan, located on the boundary of the Eurasian Plate and the Philippine Sea Plate, is among the areas with the most frequent perceptible earthquakes; more than 4000 earthquakes of various scales occur in Taiwan every year on average, among these, over 200 are perceptible earthquakes. Natural disasters such as earthquakes, typhoons, and



torrential rains often cause severe damage to public construction and heavy injuries and losses of life and property. Particularly, because of the abnormal global climate, the impact of typhoons and torrential

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Table 1. Bridges damaged by typhoons.

Typhoons	Bridges	Number of Casualties
Bilis, 2000	Gao Ping Bridge	Twenty-two road users fell from the bridge and were injured.
Toraji, 2001	Dong Men Bridge, Taichung City	One death and one person missing.
Sinlaku, 2008	Hou Feng Bridge	Two deaths and people missing.
Morakot, 2009	Shuan Yuan Bridge	Many people were missing.

rains on Taiwan has increased. Natural disasters are tending toward a large-scale, high-frequency, and complex trend. Europe and Central and South America in 2004 and the United States in 2005 all suffered unprecedented large flooding, and Taiwan is no exception. Because Taiwan is located in an area with frequent plum rain, convective thunderstorms in summer afternoons, typhoons, and northeastern monsoons, Taiwan has abundant rainfall; the annual average rainfall can be as high as 2500 mm. In addition, because the topography of Taiwan is steep, the rainfall intensities are concentrated. With 3.5 typhoons every year on average, and dozens of torrential rains, Taiwan's average annual loss is more than 12.8 billion NTD.

Disaster prevention by strengthening bridges against typhoons and floods is an urgent and crucial issue. Typhoon Morakot caused severe damage to bridges in August 2009; more than 100 bridges in central and northern Taiwan fractured, and over 40 bridges within the jurisdiction of the Directorate General of Highways collapsed. Additionally, 16 bridge piers of the ShuanYuan Bridge collapsed, and the deck broke and fell 460 m, causing vehicles to fall into the river underneath leaving people injured or missing. Additionally, Typhoon Sinlaku destroyed Hou Feng Bridge in 2008, resulting in 2 deaths and 4 people missing. Typhoons occur in Taiwan every year, and with the transition effect of global warming, the problems of typhoons and floods will increase in severity. Consequently, the conditions will be increasingly harsh on the economy, the lives and properties of people, and bridges that connect traffic and transportation. Particularly, the midstream and downstream of the main channels of rivers in western Taiwan have declined significantly over the last 10 years. Erosion by floods poses a serious threat to the safety of river-crossing bridges; thus, disaster prevention is urgently required. Crucial tasks include ensuring the functionalities of bridges during typhoons and floods, reducing the occurrence of bridge collapses, and issuing instant alerts of dangerous bridges as quickly as possible to enable



engineering personnel of traffic maintenance and management units to adopt the appropriate measures promptly to reduce disasters from occurring and prevent secondary disasters. All these tasks rely on the development and verification of an instant erosion monitoring system and the interpretation of related monitoring data to assess bridge stability and safety.

Most early monitoring was conducted using host computers or specific embedded monitoring systems; mobile data displays and telemetry became available after the invention of mobile device. Smart phones have become increasingly developed and popular in recent years. The applied techniques of these devices are no longer limited to entertaining and communication. Increasing business services and academic studies have focused on mobile phones, especially after Google opened its Android system to the public.

2. Development of a Bridge Scouring Real-time Monitoring System

2.1 Sensing and Monitoring Network

Conventional monitoring device systems have several disadvantages. The integration of system wires and various devices is complex for conventional systems, and a substantial uninterruptible power supply (UPS) is required in case of occasional power failures during typhoons. UPS not only requires space but also causes problems such as depleting resources and increasing the vulnerability of sensors and equipment. Additionally, the monitoring devices are expensive; thus, they are typically only installed at single points in crucial locations and cannot form a wide-area dense surface layout. Conventional systems also cannot be integrated with other types of sensors, such as precipitation gauges, water level gauges, anemometers, accelerometers, clinometers, and pressure gauges, on the same disaster to monitor multiple disasters. Therefore, the latest scientific technologies are required to develop an advanced monitoring technique that is appropriate for future use on different techniques and purposes. Research and applications of smart sensing and monitoring network techniques, including optical fiber sensors (for example, fiber Bragg grating sensors) and wireless monitoring networks (ZigBee network), are valuable for the prevention, reduction, and rescue response for various natural and man-made disasters.

The development trend of wireless network systems involves placing the sensing, recognition, and calculation functions of microprocessors and wireless communicators on a single silicon chip. Different sensing devices can connect with each other through various

signal transmission architectures, such as the clustering method (mesh network and cluster network). Therefore, sensing, recognition, and calculation capabilities and wireless communication networks will be widespread and have a profound effect on people's lifestyles in the near future. For example, installation of such a system on bridges and buildings enables long-term monitoring and diagnosis of the safety of bridges and buildings during typical conditions. However, when an earthquake occurs and damages bridges and buildings, this wireless transmission and sensing system can also send instant information on whether the bridges and buildings have collapsed, or the collapse conditions of vital disaster rescue organizations such as hospitals. The system can also connect instantly with earthquake rescue systems and vital systems, and display the vital rescue routes in disaster areas in real-time to enable disaster prevention and rescue units to implement resource management and disaster relief. Additionally, smart sensing and monitoring techniques are even suitable for the real-time monitoring of water levels during typhoons and floods. Through the developmental designs and tests of related microelectromechanical systems (MEMS) sensors and the development of wireless monitoring techniques, damage from natural disasters can be minimized. Obtained data can also be used as references by the relevant government authorities for making decisions on emergency responses. The operational concept of the smart sensing and monitoring network is shown in Figure 1.

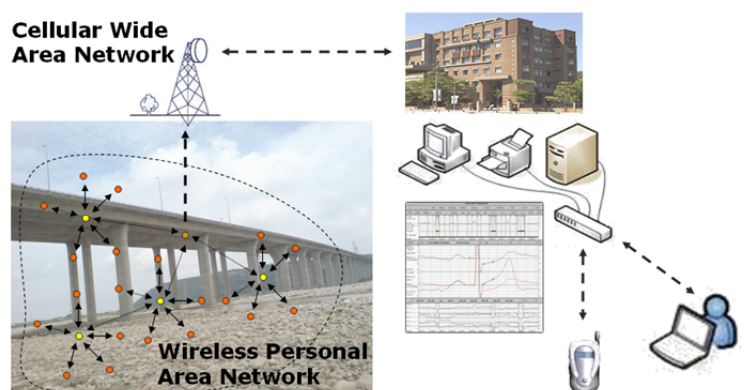


Figure 1. Schematic diagram of the smart sensing and monitoring network.

2.2 Wireless Monitoring Network Techniques

With the advancement of science and technological developments, electronic technologies and wireless transmission technologies have become increasingly common. Conventional wired monitoring systems are developing in wireless, small, integrated network, economical, and power-saving trends. Wireless

sensor networks (WSNs) are developed by combining monitoring devices with wireless transmission. Under the wireless sensor network architecture, sensor nodes are designed to have features such as power-saving, low cost, small, and data capturing abilities. Sensor nodes are similar to small computers; they are equipped with simple sensing, computing, and wireless transmission devices. Captured data are returned to data collectors through wireless transmission devices after simple computing processes. Finally, the condition of bridges can be analyzed according to the data collected by the data acquisition.

The architecture of wireless networks can be divided into the physical layer, medium access control, network layer, and application layer; the hardware comprises the bottom layer and the use and operation layers are the top layers. ZigBee network and transmission behaviors are defined from the physical to the network layers. Wireless sensing network transmission protocols include 802.11b/g, IEEE802.15.4 (ZigBee), IEEE802.15.1 (Bluetooth), and GPRS. Factors such as bandwidth, transmission rates, easy access, ease of use, economy of long-term use, and popular technical experience must be considered when programming and selecting a measurement transmission system. The wireless transmission systems most commonly used in daily life are 802.11b/g; the protocols are used widely in both indoor and outdoor internet extensions and comprise the basic equipment of numerous notebooks. The frequency for 802.11b/g systems is 2.4 GHz, the maximum transmission rate is 11 Mbps for 802.11b and 54 Mbps for 802.11g; with a wireless base station, the transmission distance can reach 500 m, and the systems have the advantage of widespread technical experience. The application of ZigBee wireless communication techniques for the construction of a wireless monitoring network system can be summarized with the following features:

- (1) **Easy on-site installation that significantly increases the economic efficiency:** Data is transmitted through wireless communication techniques; therefore, the complex wiring required for conventional monitoring systems can be eliminated, significantly reducing the construction and manpower costs. Additionally, the system uses a microsensor with small monitoring element modules; thus, the system can be installed in required locations according to on-site conditions.
- (2) **Data confidentiality and reliability:** ZigBee provides a function for data integrity inspection and also contains an encryption algorithm to ensure data confidentiality. ZigBee also includes a mechanism to prevent signal collision; this function

prevents potential conflicts from occurring when sending or receiving data. Each sent or received data packet must be confirmed by the receiver or sender before performing the subsequent step to ensure data reliability.

- (3) **Low hardware costs:** The price for ZigBee transmission modules is expected to be reduced to between 1.5 and 2.5 USD as the market expands and the technical layer advances. Additionally, the microsensor used in the system is a crystal micromechanical device produced in semiconductor manufacturing processes. Mass production results in the extremely low cost of single sensor elements; therefore, the entire system has great economic competitiveness compared to that of conventional systems.
- (4) **Non-directional and low power consumption:** The ZigBee wireless communication technique transmits data through radio waves. The sender and receiver ends are not required to be directionally aligned and transmission is almost unaffected by intermediate obstructions. However, the penetration of radio waves in reinforced concrete structures must be discussed and studied further. Nevertheless, most sensors are installed on the exteriors of on-site bridge structures. Regarding sensor modules that must be embedded, the sensor elements can be connected with the wireless data transmission module using short distance wiring; data transmission can be ensured if the wireless transmission module is exposed on the exterior of the structure.
- (5) **Large network capacity:** Presently, one ZigBee network can accommodate a maximum of 254 monitoring points, and a maximum of 100 ZigBee networks can exist concurrently within a region. This system is ideal for civil engineering structures that require numerous sensor elements. In addition to providing more comprehensive measured data, numerous sensor elements can compensate for potential data losses caused by malfunctioning or damaged sensor elements.

2.3 MEMS Sensors

Microelectromechanical systems (MEMS) are defined as smart micro systems that have sensing, processing, or actuating functions; they contain single or multiple chips with two or more integrated electronic, mechanical, optical, chemistry, biological, magnetic, or other properties. A MEMS device is a micro device that contains both electronic and mechanical functions, providing both the processing ability of electronic signals and the motor ability of mechanical structures. MEMS



are manufactured by various microfabrication technologies; the current major methods include silicon-based (silicon manufacturing process), Lithographie, Galvanoformung, Abformung (LIGA), and polymer (high molecular polymer) techniques. MEMS are widely applied in various fields including manufacturing, automations, information and communication, aerospace industry, transportation, civil engineering, environmental protection, agriculture, forestry, fishery, and animal husbandry. MEMS originated in the mid-1960s with the concept of manufacturing mechanical structures on silicon chips in the manufacturing process of semiconductors. The concept attracted numerous people to research the MEMS technique. Essentially, MEMS use the semiconductor manufacturing technique to integrate electronic and mechanical functions and generate micro devices. The major product categories are accelerometers, gyroscopes, pressure gauges, optical communication components, digital light source processing (DLP), ink-jet heads, and RF wireless sensing elements. MEMS have been increasingly applied in various products including vehicle tire pressure measurements, optical communication networks, projectors, sensor networks, digital microphones, clock oscillators, and game machines. MEMS also play a key role in the research of new generation memory techniques, biochips, display technologies, and new energies.

3. Bridge Scour Sensor

This study proposes four scour sensors. Through on-site installation, we compare and verify the performance of each system during and before typhoons and floods to estimate the efficacy of each scour sensor system.

3.1 Fiber Scouring Sensors

A fiber Bragg grating (FBG) provides multiplexing and direct instant measuring functions. This is because the feedback light source of the fiber sensor technique is more rapid and accurate than that of conventional sensor systems, making it suitable for use in harsh environments. As fiber sensor techniques develop, the applications of fiber sensors increase. The advantages of fiber sensors include the following: (1) small size, minimal weight, and great flexibility; (2) not vulnerable to electromagnetic and radiation interference; (3) low transmission losses; (4) substantial sensibility; (5) maintains accuracy, stability, and reliability for long-term use; (6) excellent resistance to harsh environments and remote transmission; (7) large bandwidth; and (8) it has a multiplexing feature. Fiber scour sensors have been successfully employed to monitor instant changes of scouring depth and water levels. With appropriate protection measures, fiber scour sensors can be effectively applied to on-site experiments for long-term monitoring. FBG provides multiplexing and direct instant measurement functions. Additionally, because the feedback light source of the fiber sensor technique is more rapid and accurate than that of conventional sensor systems, it is suitable for use in harsh environments. Fiber scour sensors can monitor the scouring conditions of riverbeds in real-time, transmitting signals through optical fiber networks to monitoring centers. When water levels reach the warning scour depth, the sensor provides early warnings for related personnel to take appropriate responding measures (Figure 2).

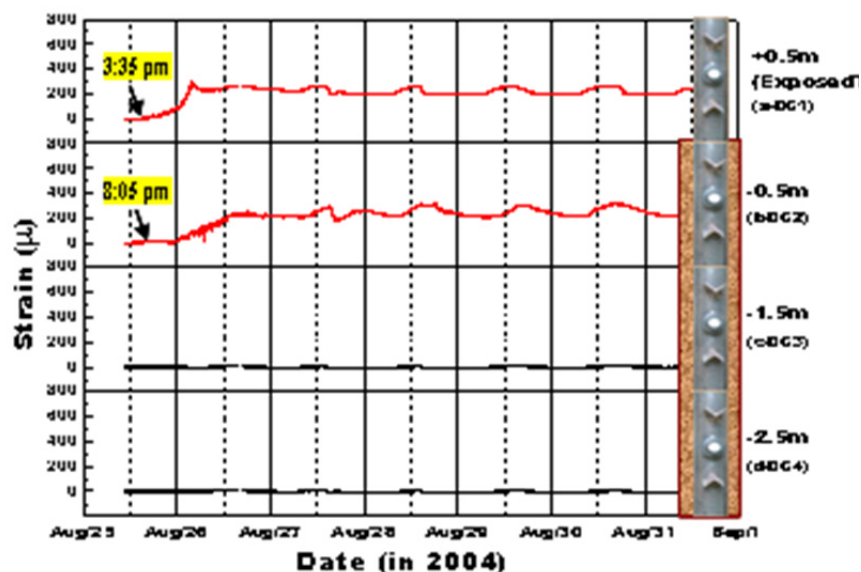


Figure 2. Fiber scouring sensors.

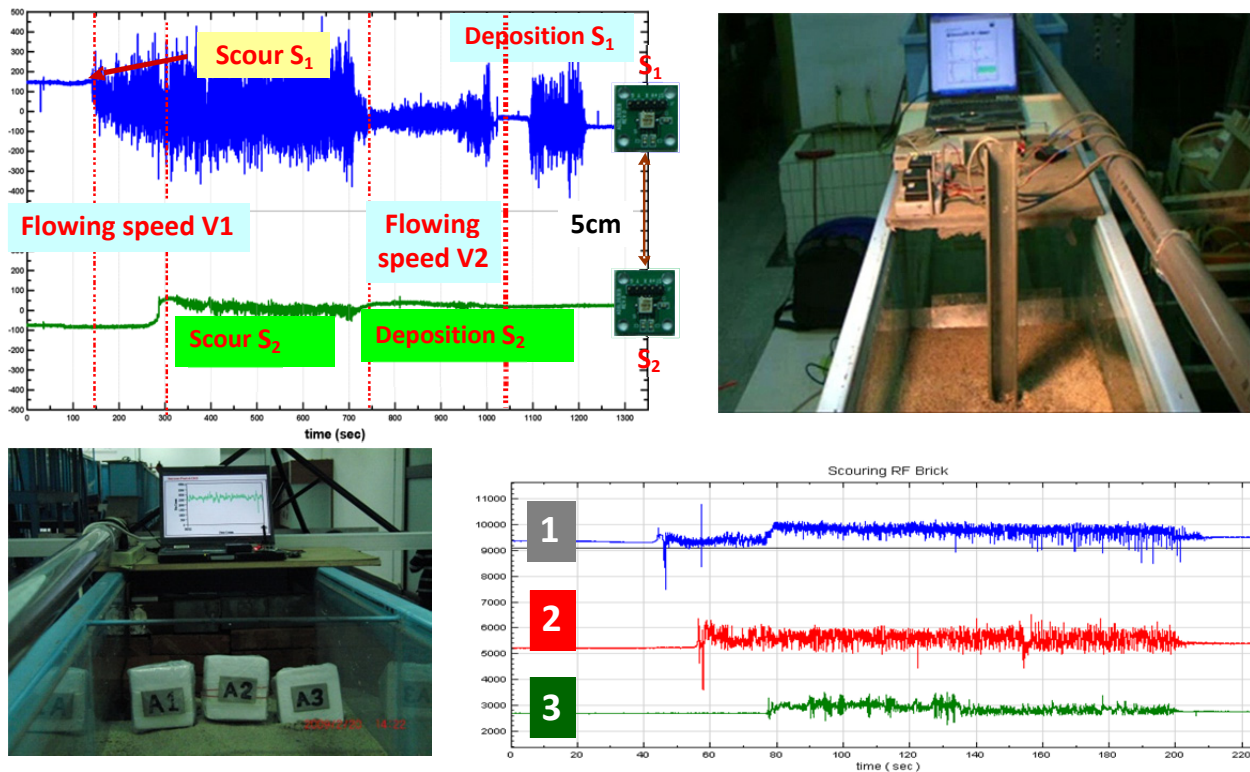


Figure 3. Wireless network H-beam scouring bricks and floating bricks.

3.2 Wireless Network Scouring Bricks

The wireless network scour bricks H-beam system uses sensor made by MEMS processes. The sensor elements are small sized and low in cost and made into bricks through basic processing. When a brick is flushed, microsensor elements can measure the vibration signals generated by water currents. The signals are sent back to monitoring centers through the wireless sensor network from the microsensor. The scouring monitoring device was installed in an artificial sink, and measured results are shown in Figure 3.

3.3 Wireless Floating Bricks

In this study, wireless floating bricks are modified RF elements. The floating bricks are small signaling devices that have a radio transmitter function. Wireless floating bricks should be buried near a bridge; these bricks do not send signals in a static state because the buried location has not been scoured by a flood. However, as the floating bricks are exposed because of scouring, the built-in mechanical device activates the internal transmitter system and sends packet radio signals. The receivers decode, transmit, and identify the scouring depth of the riverbed after receiving the signal.

This monitoring method is both economical and simple. When buried under riverbeds, wireless floating bricks can detect the scouring depth of each section of the riverbed as a flood peak flow passes the riverbed. However, wireless floating bricks are disposable scouring monitoring systems; each brick can only be used once. This study uses the MEMS/NEMS piezoelectricity device technique to design a wireless network floating brick. (Figure 3).

3.4 Microelectromechanical Scouring Pressure Gauges

Pressure gauges, a product generated in the MEMS manufacturing processes, measure changes in water level of flowing water when placed in water. Pressure signals include static water pressure, dynamic water pressure of flowing water, and soil pressure that results from sand deposition. The pressure gauges are not affected by dynamic water pressure when buried under a river; therefore, the depth of deposition can be determined instantly from lateral soil pressure by measuring the external subsidiary instant water height pressure (Figure 4). Therefore, the river sand deposition process and the deposition height can be determined through the signaling responses measured by the sensors.

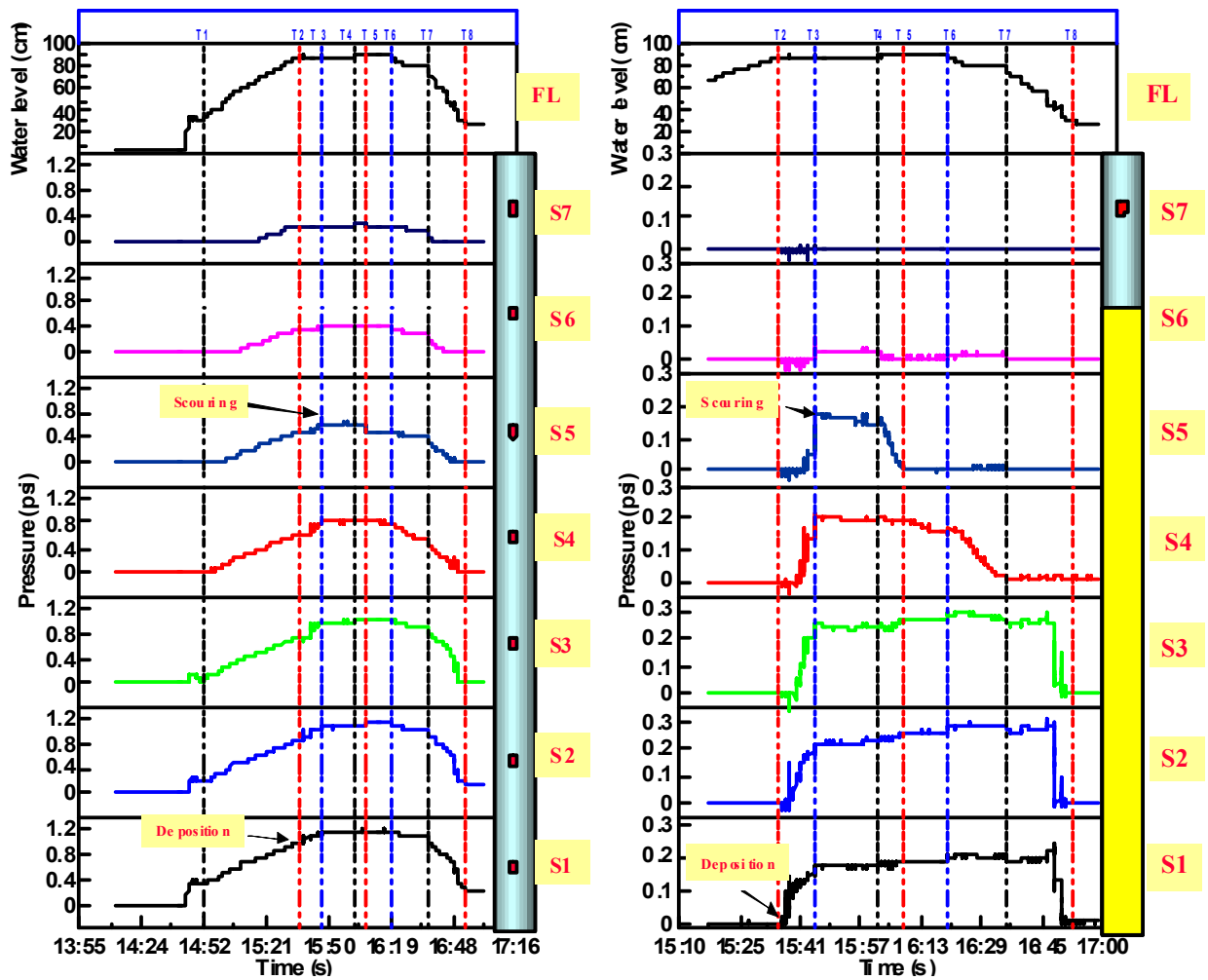


Figure 4. MEMS pressure gauges.

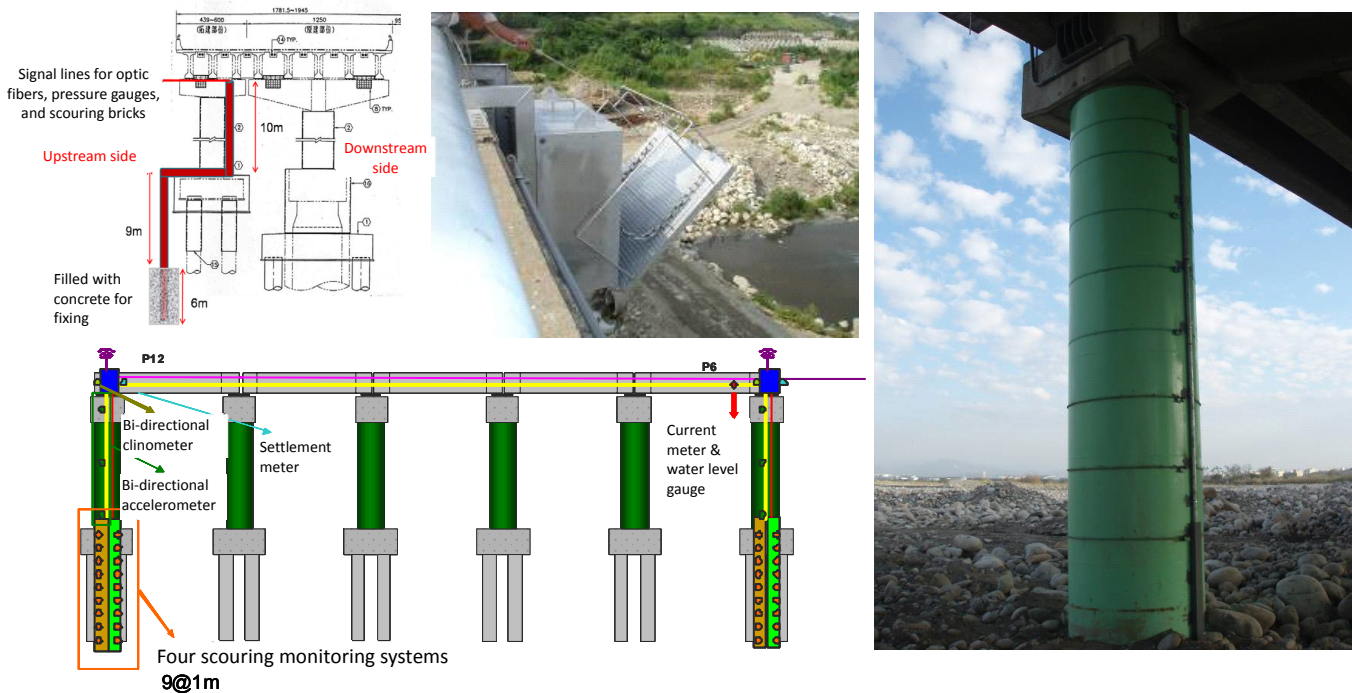


Figure 5. Schematic diagram of the scouring network system of Dajia River Bridge of National Freeway 1.



3.5 Establishment of On-Site Bridge Monitoring System

A schematic diagram of the scouring network system on Dajia River Bridge of National Freeway No. 1 is shown in Figure 5. The entire length of the monitoring tube of the system is 15 m; the bottom 6 m serves as a base for fixing the tube and the top 9 m is the monitoring tube. After tube installation, sand is refilled. Nine sets of sensors were installed 1 m apart on the upstream side of the bridge pier, and a wireless transmission module is installed on bridge pier P12. The wireless transmission module transmits signals directly to a monitoring center through a 3G net card, which allows the monitoring center at the remote end to monitor the conditions of the entire bridge in real-time.

We equipped two sets of monitoring systems on the piers of the Dajia River Bridge; each set contains four types of sensing mechanisms: the MEMS scouring pressure gauge, the fiber scour sensor, the wireless network scouring brick, and the wireless network floating brick. Additionally, P6 and P12 piers are both equipped with three dual-axis accelerometers at the top, middle, and bottom of the pier to monitor pier vibration. The bridge deck was also installed with a dual-axis accelerometer and a clinometer to monitor the vibration and tilt level of the deck. To measure the settlement phenomenon of the piers that may occur because of scouring, clinometers are installed on the two piers.

Current meters and water level gauges are installed on Pier P6.

3.6 Dajia River Bridge of National Freeway 3

The construction of Dajia River Bridge of National Freeway 3 is similar to that of Dajia River Bridge of National Freeway 1. As shown in Figure 6, the bottom 6 m of the monitoring tube is used for fixing and the top 9 m is used for monitoring. The difference between the two bridges is the network transmission configurations. As shown in Figure 6, P28 monitoring tube and other sensors first transmit data to wireless network sensors, the data is then transmitted to Pier P24 through the ZigBee wireless network. Subsequently, Pier P24 transmits data back to monitoring centers using an ADSL router. This router is further equipped with a 3G net card as a backup transmission system in case problems to the wired network occur. The backup net card provides the monitoring equipment for a more reliable transmission system during typhoons and floods. Additionally, UPS is installed on both National Freeway 1 and National Freeway 3. In case power failures occur during a natural disaster, the backup power allows uninterrupted signal transmission; the UPSs can also stabilize the input power. Pier P24 is further equipped with a network camera with infrared light around the lens to allow photography of riverbed conditions and water level changes at night.

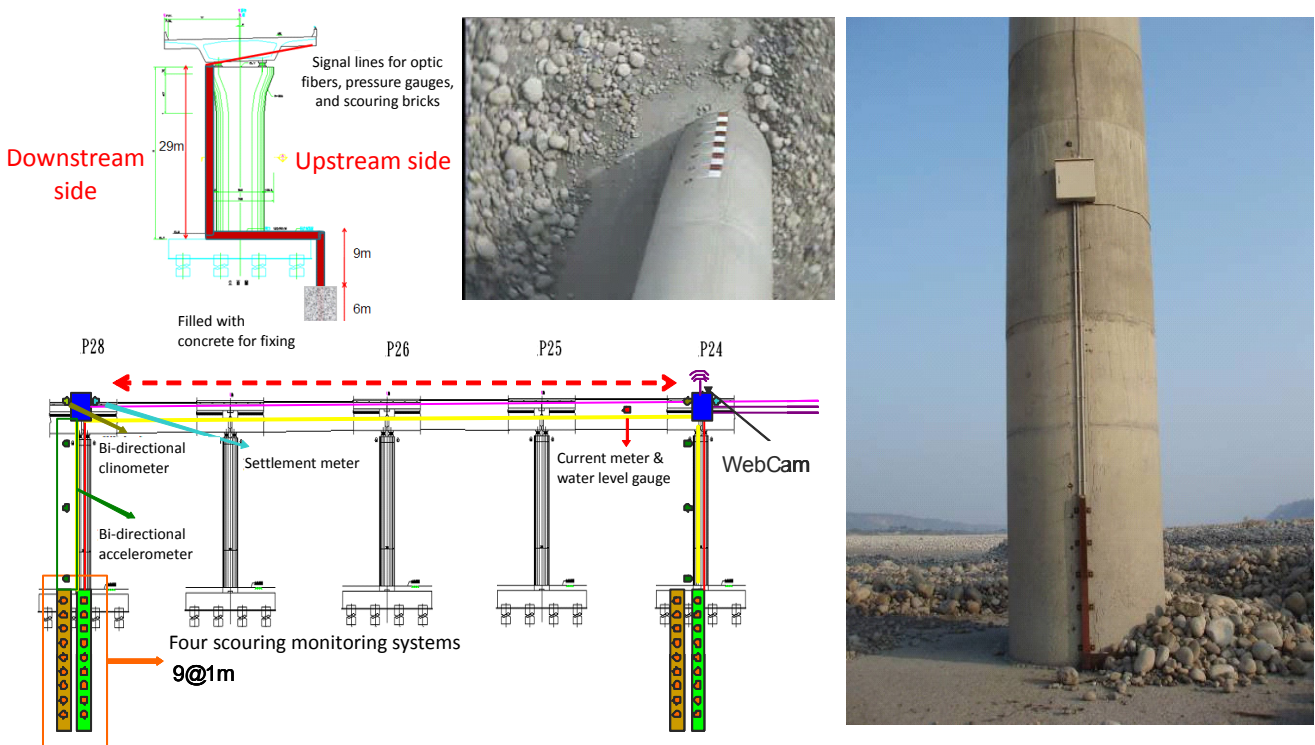


Figure 6. Schematic diagram of the scouring network system of Dajia River Bridge of National Freeway 3.

3.7 Real-time Monitoring Platform Webpage

Various sensors are used in different areas, for example, different sensors are used for monitoring bridges, temperature and humidity, scouring, water levels, water pressure, and flow velocity. Different areas require various devices for the corresponding areas. Additionally, integrating devices from different areas was a substantial project in the past. Wireless network sensors provide each research area with a shared platform for concurrent and real-time data monitoring and allow users to obtain the required data for analyses. The shared platform effectively saves manpower, improves research efficiency, and provides instant feedback to the engineering sector, ultimately enhancing traffic safety.

The integrated platform webpage is shown in Figure 7. The webpage displays data of each bridge pier, which is divided into two rows. The first row lists the estimated data; the river water level is inferred through the rainfall data obtained upstream and weather forecast information, and the flow velocity and the scouring depth are deduced by estimating the return period. The second row lists the real-time monitoring data. On-site monitoring systems collect and send data directly to the display platform. Measured data are also transmitted to the analysis platform for verification to improve the accuracy of forecasting. Once the water level, flow velocity, and scouring depth data become available, the safety factor can be determined through bridge safety and stability analyses to ensure the safety of the bridge. Once a bridge reaches the warning level or actuating value, the system can deliver messages through message machines to alert related personnel. Regarding the information shown on the webpage, the same information is displayed for the two bridge piers of a bridge because a water level sensor and a flow rate sensor were installed on each bridge. The advanced homepage is an information platform designed for academic researchers; researchers can capture monitored data through this platform. If further analyses are required, researchers can select a corresponding sensor and export data at various time points to effectively increase the sampling efficiency. Furthermore, the related personnel can remotely operate the system during typhoons and floods to ensure their safety. Through automatic back-end computer analysis, the system automatically issues warnings when an emergency occurs; therefore, the operators are not required to focus on monitoring the platform continuously to monitor the safety of bridges.

墩號	時間	水位EL. (m)	流速 (m/s)	冲刷深 (m)	安全係數 F.S.
國道1號 P6墩 163k+753	未來一小時 水理模擬預報	10/09/02 12:00:00	171.26	*	*
	即時監測	10/09/02 11:15:49	171.19	0.32	0
國道1號 P12墩 163k+963	未來一小時 水理模擬預報	10/09/02 12:00:00	171.26	*	*
	即時監測	10/09/02 11:15:49	171.19	0.32	0
國道3號 P24墩 167k+911	未來一小時 水理模擬預報	10/09/02 12:00:00	71.43	*	*
	即時監測	10/09/02 11:16:22	71.00	0.64	0
國道3號 P28墩 168k+091	未來一小時 水理模擬預報	10/09/02 12:00:00	71.43	*	*
	即時監測	10/09/02 11:16:22	71.00	0.64	0

Figure 7. The bridge instant monitoring platform.

4. Android LBS Mobile Positioning Service System

Currently, the most popular device service on smart phones, including iPhone of Apple Inc. and Android of Google, is location-based service (LBS). As defined in Wikipedia, "LBS is an information or entertainment service, accessible with mobile devices through the mobile network and utilizing the ability to make use of the geographical position of the mobile device." LBS is one type of location service; it locates the position of a user through mobile devices equipped with a positioning technique, and provides the required application service according to the user's location. LBS can be achieved through GPS and network communication on typical mobile devices. LBS acquires the location information of a user (geographic coordinates) at the mobile terminal (such as smart phones and tablets) through the wireless communication network (such as GSM network and CDMA network) or external positioning (such as GPS) of mobile operators, providing a value-added service to users with the support of the GIS platform.

Integrating LBS on mobile phones has become a global trend. Numerous manufacturers have used the geographical information provided by LBS and related information to increase the value of shops and manufacturers to provide instant information including promotions, exhibition activities, learning facilities reminders, and historical and cultural on-site backgrounds. Numerous positioning-related products have been developed since its launch in the market. Particularly, as the integrated devices of GPS and mobile communication become increasing popular, the number of added-value services combining positioning and information techniques increases. LBS is achieved by calculating the geographic location of a user through the

built-in GPS or other auxiliary positioning method; the coordinates of the user and other required information are subsequently transmitted to LBS providers to combine the coordinates in a geographic information system. This processed data can then be used in positioning-related applications. Finally, the applications or services are transmitted to the mobile devices or other user application systems. Therefore, LBS has a wide application range including navigation, information inquiries, mobile commerce, tracing of vulnerable groups, and emergency rescues. For example, when danger is detected on a bridge and the bridge must be closed, warnings can be issued to people near the bridge (for example, within 3 km) using LBS to prevent losses of life and property.

4.1 LBS Bridge Monitoring Positioning System

The combined exhibition of a mobile display interface and geographical information systems use the monitoring and geographical information system of the Android environment developed by Android SDK with the application protocol of MVC architecture. Figure 8 shows the geographical information system implementation and monitoring data integration plan. The content mainly focuses on developing the server for an LBS geographical information system, Android exhibition, and GPS modules.

The system is divided into the following four modules:

- (1) **Android Layout:** This layout uses images or UIs to display the captured data, and contains some application operation interfaces.
- (2) **Location Module:** Android SDK is combined with a positioning module for communication control and

with communication devices for acquiring positioning information.

- (3) **Image Socket Module:** The study team designed a network image capturing method using the existing monitoring system and combined it with the Android system for display.
- (4) **Data Parser:** Data parser defined all the rules for network communication or internal communication programs, and communicated with service hosts or related applications according to these rules.

The system architecture diagram mainly captures signals of the monitors installed on each pier; the signals include information such as water levels and scouring depth of a bridge. The information is screened and analyzed and then saved in the database of the system. The information can be divided into real-time information and forecast information. The forecast information is calculated using the forecast simulation system.

4.2 LBS Dynamic Event Feedback Modules

The database of the LBS information center is designed to allow the easy sharing of information. The LBS information center uses XML format to provide various application services for data exchange. Users can inquire on forecast information by browsing the webpage using a computer, or acquire LBS service through mobile devices equipped with GPS. A mobile device determines the position of the user through built-in GPS and uses this location when inquiring forecast information of nearby areas from the LBS information center. Finally, the results are displayed through the Geo View Module combined with Google Map to forecast information.

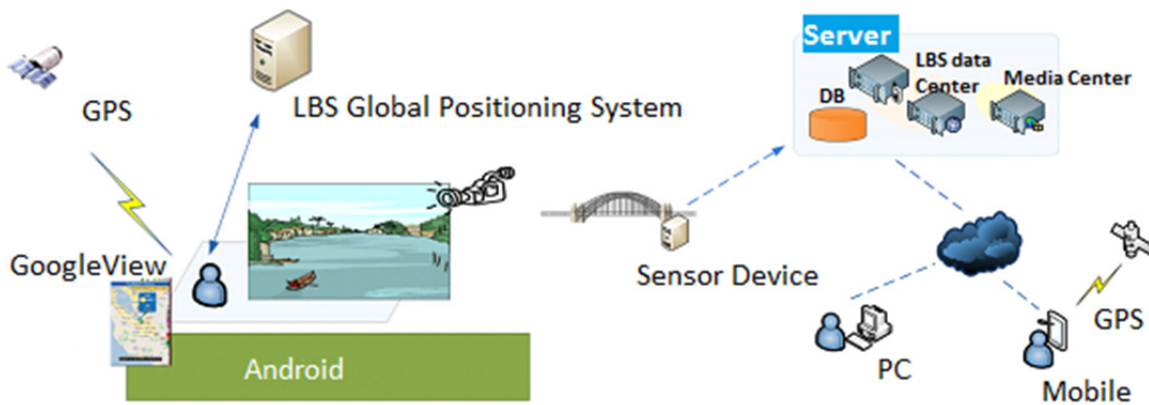


Figure 8. Android-integrated geographical information system and LBS-monitoring architecture.

4.3 The Browser End of Mobile Geographical Information

The system uses the Android system environment for mobile devices. The LBS monitoring of bridges is achieved by implementing Android Google API, which uses the modules provided by Android to obtain the LBS and combine Google Map mobile geographical information systems. Figure 9 shows the concept screen of Android mobile devices. The browser end of the mobile geographical information system mainly displays geographic information; the background service regularly captures monitored forecast information and lists the monitored warning information of locations near to the user. Simultaneous displays of images and text allow browsers to quickly and easily understand the conditions of the nearby bridges. Detailed information of a certain monitoring point can also be obtained.

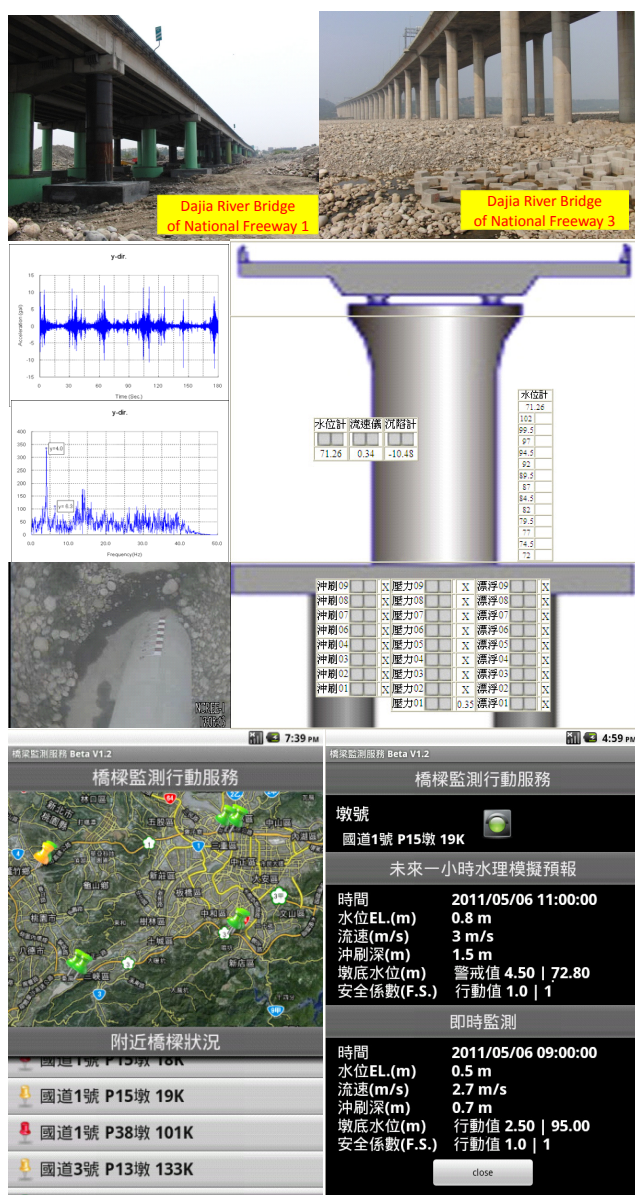


Figure 9. The user screen of LBS bridge monitoring.

5. Conclusion

The bridge scouring real-time monitoring system provides a comprehensive, instant, and functional monitoring platform to monitor the safety of bridges. Actual measurements during typhoons and floods, analysis and evaluation of the monitored results, and maintenance and adjustment of the system are still required to improve the quality of bridge research and instant and remote monitoring to effectively reduce the human and material resources needed and increase the accuracy of bridge monitoring. In harsh weather, such as during typhoons and floods, the system allows relevant personnel to monitor the conditions in real-time through the Internet. The mobile positioning technology of LBS also provides engineering personnel and bridge maintenance units with a more effective tool. The bridge scouring real-time monitoring system integrates sensors and monitoring systems of different areas and simultaneously observes the bridge conditions during daily use and during natural disasters, such as typhoons and floods, scouring, and earthquakes. The system is also used to examine and monitor the usage condition of bridges; the results provide an integration and cooperation platform for academic and engineering units.

Through the rainfall information of the Center Weather Bureau, the water management information of the system estimates the water level and volume of rivers to issue early warnings of potential disasters. The accuracy of forecast information is expected to be improved through the information analysis of measured results.

The monitoring system provides various types of sensors and monitors and measures scouring depth and water levels during typhoons and floods. The information obtained in this study was compared with the results of hydrological analyses and structural analyses to establish various parameters, such as scouring depth, water level, flow velocity, vibration frequency of bridges, and structure safety. Different assessments and practical tests were also conducted to verify the results.

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