BRIDGE HEALTH MONITORING SYSTEM BASED ON SMART DEVICES IN TAKAMATSU BRIDGE

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1. INTRODUCTION

After the 2011 Great East Japan Earthquake, considering immediate occupancy judgment and safety of aging structures, rapid damage assessment of bridges such as damage localization, serviceability and restoration is realized to be important. Long-term vibration monitoring in bridges using high-density instruments is one of the straight forward measures for this purpose. This study investigates the implementation feasibility of long-term bridge health monitoring technique using smart devices. Previous study (SHRESTHA, A. etal 2015) investigated the feasibility of built-in MEMS accelerometer in smart devices for vibration-based measurement by conducting shaking table tests. In this study, a real field application test of the measurement system applied to long-term seismic-response and environment-vibration measurement of Takamatsu bridge has been carried out. First, a measurement system including a group of smart devices has been established successfully. The system is then connected to cloud server for data acquisition, and continuous measurement is taken owing to internet and power supply access on the bridge. Field measurement results of Takamatsu bridge during some recorded seismic event shows that the dynamic properties extracted from smart-device-based system is very similar to those extracted from high-quality-sensor-based system.

2. TAKAMATSU BRIDGE: OVERVIEW

The Takamatsu bridge, as shown in Figure 1 was built in 1982 at Miyazaki, Japan. It is a PC box continued girder bridge with 7 spans, 444 m in length and a pile basement. The bridge has BP bearing at abutments and pin bearing at the pier part and with a Gilber hinge at 3rd and 5th span. This bridge connects two parts of the city separated by Oyodo-Gawa river and maintaining the transportation function as a key for resilience of this area. Therefore, long term seismic monitoring is considered as a useful way to check its functionality and damage of risk under earthquakes.

The bridge has been instrumented with four smart devices (iPhone 5s labelled as 1, 1a, 2 and 3) at three different locations of bridge, where high precision seismometer sensors (Hakusan Industrial SU501) had already been installed after the 2016 Kumamoto earthquake, thus giving measurements from both the smart devices and high precision sensors.

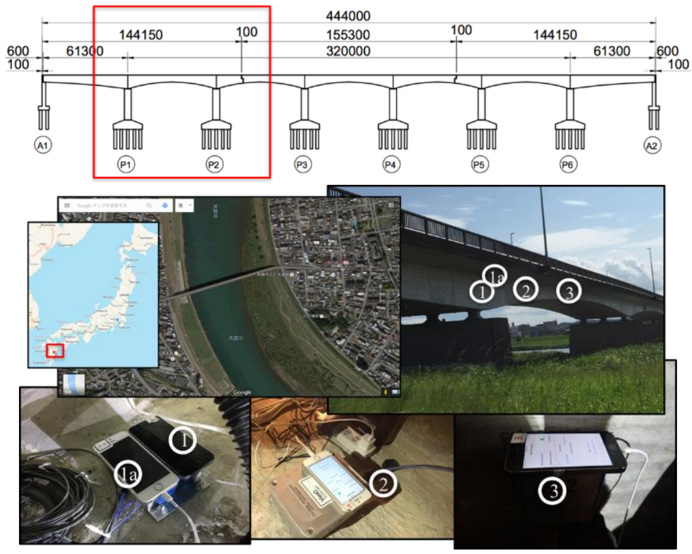

Fig. 1 Installation of smart devices on Takamatsu bridge

3. MEASUREMENT APPLICATION INTERFACE

Measurement Application program for smart devices was developed, which interacts with hardware and operating-system features to make the built-in MEMS sensor components available and are responsible for acquiring data, analyzing data, storing data, and transferring useful data to the cloud. The app was developed based on the Objective-C programming language in the integrated development environment Xcode. In this study, Dropbox sync API (Dropbox developer, 2014) is used as the data-restoring cloud server. Using this API, the app can read, create, and modify files. It also notifies app when the parameter-setting file in the cloud server is changed by other terminals, such that the app can respond instantly and synchronize its measurement settings to the newest command.

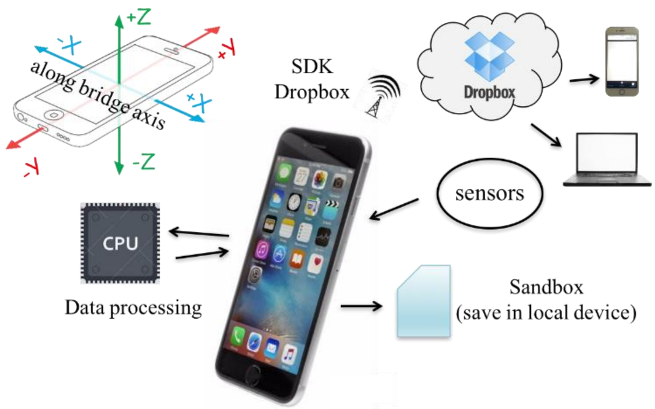

Fig. 2 Measurement system

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4. LONG-TERM BRIDGE MONITORING

After installation, 24 hours continuous measurement from all the smart devices are being performed and the recorded data can be monitored in real-time. Since the start of measurement, recordings of two smart devices at location 1 (iPhone 5s_01 and iPhone 5s_1a) were interrupted due to power issues. However, we can observe a continuous, non-interrupted measurement from two other smart devices at location 2 and 3 (iPhone 5s_02 and iPhone 5s_03) as depicted in data volume information chart in Figure 3. This continuous and stable data measurement justifies the applicability of smart devices for long-term vibration monitoring applications. With 24 hours of continuous environment-vibration measurement, the smart devices recorded 3 earthquake events from the date of installation among which the recorded acceleration waveform along bridge axis for 017/03/02 earthquake is shown in Figure 4.

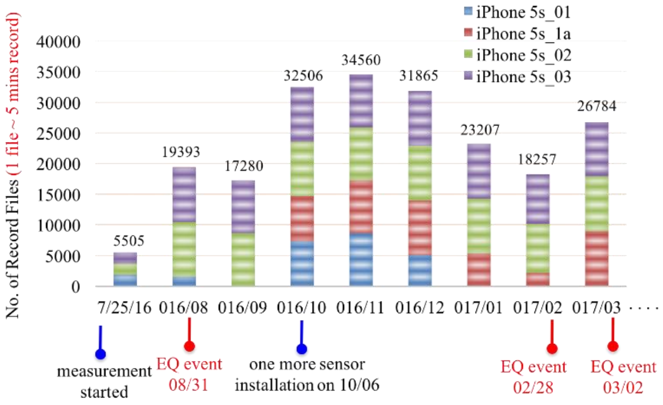

Fig. 3 Data volume chart for 24 hrs measurement

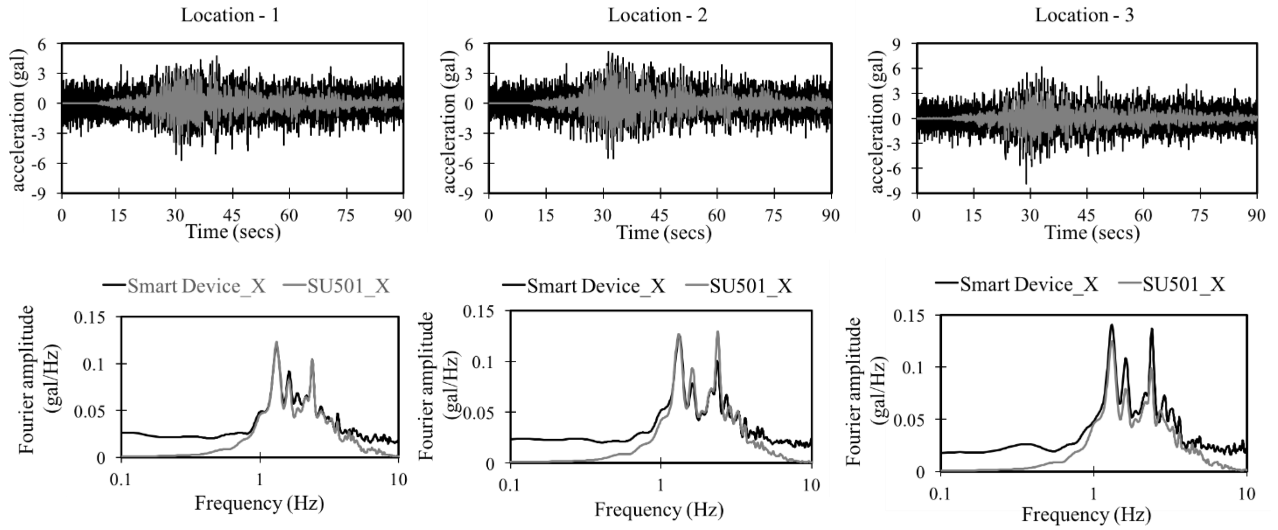

Fig. 4 Time History and Frequency Domain comparison for 017/03/02 Earthquake at 3 different location of bridge

From Figure 4, it can be seen that the waveforms measured by two systems are almost same. The fundamental natural frequency identified from Fourier spectrum by selecting the frequency corresponding to the highest peak is also comparable with the high-quality-sensor as shown in Table 1, thereby justifying the accuracy of using smart devices. Moreover, for further analytical purposes in future, the system shall also be tested to see if it can produce valuable modal-identification results for SHM.

Table 1. Dynamic properties comparison between smart device and Hakusan sensor measurement along bridge longitudinal direction

Location	Earthquake recorded date	016/08/31		017/02/28		017/03/02	
		freq (Hz)	amp (gal/Hz)	freq (Hz)	amp (gal/Hz)	freq (Hz)	amp (gal/Hz)
Location 1	Smart device	-	-	3.765	0.107	1.311	0.12
	Hakusan	-	-	3.732	0.100	1.311	0.123
Location 2	Smart device	1.467	0.127	2.774	0.070	1.311	0.126
	Hakusan	1.467	0.119	2.762	0.060	1.311	0.127
Location 3	Smart device	1.467	0.116	2.733	0.067	1.311	0.140
	Hakusan	1.467	0.104	2.749	0.060	1.311	0.125

5. CONCLUSIONS

In general, smart-device-based measurement system naturally possess the three prerequisites of a vibration measurement system, i.e. sensors, data transfer, and GPS. However, the system is limited to moderate-to-strong earthquakes as accurate waveform data concerning earthquakes with smaller magnitudes are hidden by noise components of approximately ± 5 gal. Nevertheless, with improvements in the resolution and sensitivity of MEMS accelerometers in the future, the proposed system can be expected to be applied to observation of smaller earthquakes as well.

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