A Mobile Sensor Network System for Sound and Vibration

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ABSTRACT

The smartphone has become a powerful computing device and is equipped with various sensors due to the advancement of sensor technology. In this study, we investigated whether the built-in accelerometer sensor of a smartphone can replace the traditional SHM measuring device, an accelerometer sensor. To compare and analyze the performance, we conducted a modal analysis using a small-sized PCB accelerometer and compared it with the traditional device on a steel frame specimen.

INTRODUCTION

SHM (Structural Health Monitoring) is a critical technology for ensuring safety, economy, and preventative approaches in the field of structural integrity monitoring. It plays a crucial role in monitoring the health of various structures, including public facilities such as buildings, bridges, and towers, as well as infrastructure such as roads, ports, and airports, and transportation systems such as planes, cars, and trains [1-4]. The key technology of SHM is to monitor and perform maintenance operations on the structural integrity and safety of structures, thereby extending the lifespan of the structures and ensuring people's safety [5]. Using SHM has a clear advantage over conducting periodic inspections and maintenance work at fixed intervals, as it enables rapid response to problems that arise, thereby reducing repair costs. However, the aging of measurement equipment is one of the major issues in the SHM field. This is mainly due to the limited lifespan of sensors or hardware [6]. Existing SHM measurement equipment is mostly expensive specialized equipment, and the cost of upgrading to the latest technology or replacing sensors is very high, making it difficult to cope with aging problems. Additionally, when new technologies or methodologies emerge, existing equipment may be difficult to adapt, and there are often cases where new equipment must be purchased. To address these issues, measurement systems are evolving with new technologies such as wireless sensor networks and mobile sensors [7]. These technologies use inexpensive sensors and can be relatively easily upgraded using wireless communication, unlike existing dedicated SHM measurement equipment. Furthermore, such technologies can be applied to a wider range of structures, attracting significant attention in the SHM field [8].

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In this study, we propose using smartphones as SHM measurement devices, which are now powerful computing devices that are too powerful to be merely considered for communication purposes. Smartphones have various sensors such as accelerometers, gyroscopes, microphones, cameras, etc., thanks to the development of sensor technology. In fact, many studies have compared smartphone sensors to conventional equipment for vibration measurement and demonstrated their potential as measurement devices.

Carlos[9] found that this method is a low-cost and accessible way to track motion in physics experiments, and the success of these measurements demonstrates the feasibility of using a mobile phone acceleration sensor in the general physics laboratory. D′Alessandro and D′Anna[10] explore the suitability of low-cost three-axis MEMS accelerometers, specifically the LIS331DLH sensor found in iPhones, for strong-motion seismology. The authors conducted tests and found that MEMS accelerometers provide adequate sensitivity and noise level to be applicable to earthquake strong-motion acquisition. Zhao[11] presents an experimental study on new techniques for monitoring the soundness of bridges using smartphones and demonstrates the accuracy and reliability of potential approaches that can revolutionize bridge maintenance and safety. As such, the accuracy of smartphones in vibration measurement has been demonstrated through comparisons with commercially available equipment. However, previous studies on smartphone accelerometer measurements have mainly focused on general measurement purposes and there are no examples of analyzing modal characteristics of building structures that require more sophisticated measurements. In this paper, we compare the results of modal analysis using smartphone accelerometers and PCB miniature accelerometers in a three-story steel frame experimental model.

MOBILE SENSOR NETWORK

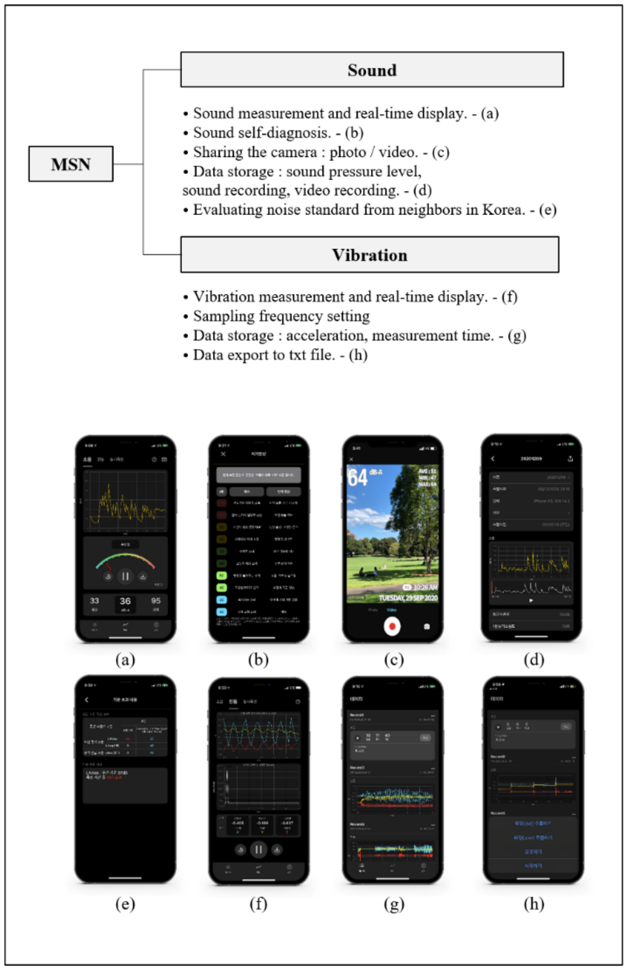

Figure 1. Relevant screens from MSN interface.

The Mobile Sensor Network system developed in this study supports both iOS and Android platforms in the form of an application. Its main functions include sound and vibration measurement, back-end server data storage, and time synchronization. Figure 1 shows the interface for each function of MSN.

Sound feature provides real-time visualization of measurement data and (a) diagnoses the sound level of the current measured space by comparing it with representative noise sources (b). It shares functionality with the camera to capture the environment with photos or videos while measuring sound (c). The measured sound data is stored as sound pressure level, sound recording file, or video recording type (d), and the stored sound pressure level (dB) is evaluated by comparing it with the noise standard from neighbors in Korea (e).

Vibration data is graphically displayed in real time in the time domain for xyz 3 axes (f), and the sampling frequency for data measurement can be freely selected in the settings, but verification is necessary for sampling frequencies of 200Hz or higher, as errors may occur depending on the device. The measured vibration data is stored on the back-end server in xyz 3-axis acceleration (g) and total measurement time (s), and can be exported as a txt file that allows for various post-processing analyses (h).

The MSN system consists of a master phone that commands remote measurement and storage, and node phones that measure data at the measurement locations, all of which are wirelessly connected to a backend server. The backend server is developed using the Python language and the Fast API framework, while the client development language is Dart and the framework is Flutter.

Just before measuring, all node phones perform time sync through Arduino and connect to the backend server to establish a connection with the master phone. When the start button is pressed on the master phone to start the measurement, the measurement time is entered and the backend server instructs the node phones with the inputted time. The instructed node phones simultaneously measure the acceleration, and the results are graphed in real-time and stored in the server. The stored data is then output to the master phone for display on the screen.

EXPERIMENTAL DETAILS

In this paper, a comparison is made between a commercial accelerometer and the built-in accelerometer in a smartphone. The commercial accelerometer used in the study is the model 333B50 from PCB Piezotronics, while the smartphone used is the Samsung Galaxy S10 SM-G973. The built-in sensor in the smartphone is the LSM6DS0.

Figure 2. Photograph of steel frame and sensors.

The experimental model used in this study is a 3-story steel moment frame with a single bay of dimensions 200mm x 100mm x 400mm. The modulus of elasticity and yield strength of the steel used in the frame model are 206 GPa and 235.3 MPa, respectively. The diagonal bracing was installed on only one side to minimize the displacement in the direction of the side with a single span. The smartphones and PCB 333 B50 were attached to plates above and below each floor, as shown in Fig. 2.

RESULT AND DISCUSSION

Raw data

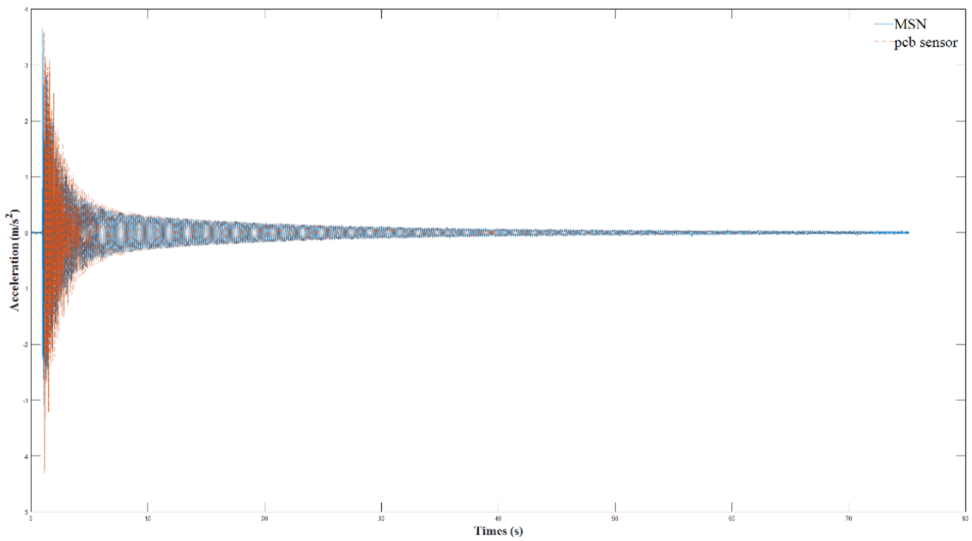

Figure 3. Photograph of steel frame and sensors.

Impact testing was performed once on the top layer using an impact hammer, and acceleration data was measured for a 4-layer PCB 333B50 and MSN. Fig. 3 represents the acceleration values over time for the top layer of the MSN and the PCB accelerometer. The maximum acceleration recorded is 3.68 m/s^2, and the total measurement duration is 80s. It can be observed that the MSN closely follows the same acceleration pattern as the PCB accelerometer

Mode frequency

TABLE I. Comparison of mode frequency between PCB and MSN

Sensor	1st (Hz)	2nd(Hz)	3rd(Hz)
PCB	6.07	20.92	36.85
MSN	6.06	20.92	36.86
Error (%)	0.16	0	0.03

The sampling frequency of the PCB accelerometer is 256 Hz, while the sampling frequency of the MSN is 200 Hz. Sampling frequencies higher than this are deemed inappropriate for measurement using a smartphone. Therefore, a Samsung smartphone was selected for the experiment after careful consideration to ensure accurate data acquisition at a rate of 200 samples per second.

FFT analysis revealed that the mode frequencies 1-3 were accurately identified by the MSN, as demonstrated in Table 1, with a high level of precision matching the PCB accelerometer.

Mode shape

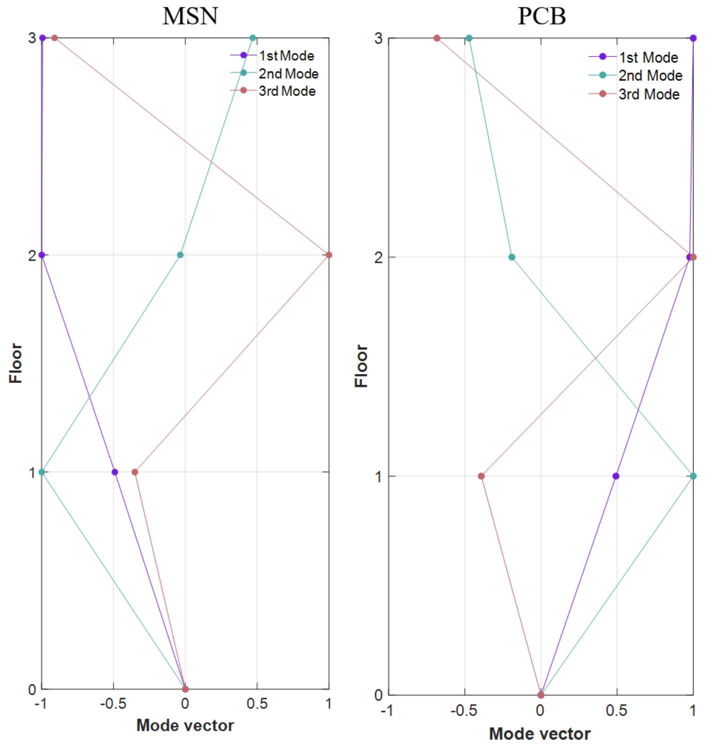

Figure 4. Comparison of mode frequency between PCB and MSN

Fig. 4 depicts the relative values of mode vectors for each floor, with the ground level as the reference. The connected lines represent the 1st to 3rd mode shapes of the test specimen undergoing vibration induced by the impact hammer load. In this study, although the mode vectors were not accurately identified with high precision, as with the mode frequencies, it was observed that the raw data obtained solely from the smartphone, without any post-processing, allowed for the identification of the 1st to 3rd mode shapes.

CONCLUSION

Modal analysis of a 3-story steel frame model was conducted using a mobile sensor network. The mode frequencies and mode shapes were compared and analyzed in relation to a PCB accelerometer. The convenience of performing modal analysis using readily available smartphones, regardless of on-site constraints such as power supply and wired connections, was confirmed. It was observed that modal analysis could be conducted without the need for data post-processing. By accurately determining the sampling frequency of each smartphone device and gradually reducing the acceleration level, repetitive modal analysis was performed. It is anticipated that this approach can evolve into an independent mobile sensor network system platform in ambient conditions.

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