Vibration measurement with routing-free multihop wireless sensor networks and its application to a long-span bridge

Tomonori NAGAYAMA
Associate Professor
The University of Tokyo
Tokyo, JAPAN
nagayama@bridge.t.u-tokyo.ac.jp

Makoto SUZUKI
Assistant Professor
The University of Tokyo
Tokyo JAPAN
makoto@mlab.t.u-tokyo.ac.jp

Yasutaka NARAZAKI
Graduate Student
The University of Tokyo
Tokyo, JAPAN
narazaki@bridge.t.u-tokyo.ac.jp

Hiroyuki MORIKAWA
Professor
The University of Tokyo
Tokyo JAPAN
mori@mlab.t.u-tokyo.ac.jp

Yozo FUJINO
Distinguished YNU professor
Yokohama National University,
Yokohama, JAPAN
fujino@ynu.ac.jp

Summary

Wireless sensor networks has been expected to reduce the installation cost and time of monitoring. However, the large size of structures poses difficulties. Communication distances are oftentimes shorter than the bridge scale. Elaborated plans on RF transmission and installation locations are required. The use of a flooding scheme exploiting constructive interference phenomena is proposed. This approach does not require routing; the path information does not need update. As a result, the multihop communication becomes simple and robust, allowing to realize easy and inexpensive sensor networks covering large structures. This communication method is applied to a long-span suspension bridge vibration measurement. The identified dynamic characteristics are discussed.

Keywords: vibration monitoring, wireless sensor networks, acceleration, multi-hop communication.

1. Introduction

The multihop communication network for wireless structural monitoring is not simple to implement and maintain[1]. When RF communication condition changes, the routing path need to be updated. Robust multihop network under such environmental changes tends to be complex. Suzuki et. al. [2] proposed a simple multihop reliable data collection scheme, called Choco (Fig. 1). Wireless sensor network implemented with the scheme is deployed on a long-span suspension bridge for vibration measurement. The measurement data is then analyzed to reveal the bridge's dynamic characteristics.

2. Field deployment and data analysis

The proposed scheme is implemented on the Contiki OS. The hardware utilized in this demonstration is a customized sensor node utilizing Epic core module. The sensor board and RF board provide the tri-axial acceleration measurement, IEEE 802.15.4-based RF communication, clock signal generation, synchronization with the GPS (optional) and other functionalities (Fig. 2).

An application to full-scale vibration measurement was conducted on the Rainbow Bridge, Tokyo. Because the experiment was conducted on the lower deck, the periodical passage of Yurikamome trains and the fence along the track posed a severe difficulty for the stability of the communication links across the bridge. Thirty seven wireless sensors were deployed on the rainbow bridge. The sampling frequency is 100 Hz and approximately 8000 seconds of acceleration data of ambient vibration were obtained from each sensor (Fig. 3). Data from 32 sensors with the length of 1000 seconds are analyzed for the estimation of natural frequencies and mode shapes.

Modal identification was performed using the peak-picking method. Due to the dense sensor instrumentation, the mode shapes can be examined in detail. Some mode shapes show non-smooth mode shapes (Fig. 4). In order to explain non-smooth shapes, the phases of cross power spectral density are examined. The phases of the most nodes are close to either zero or $\pi/2$ as linear lightly-damped systems would show. However, the phases of some nodes are not close to either of them. This difference indicates unexpected synchronization error or small signal level (i.e., SNR). In addition, the repeatability of the modal identification is examined by splitting the data into short pieces and by applying modal identification to each piece. The identified mode shapes show large variation. This variation can be due to the short length of splitted date sets, insufficient excitation, too small SNR, and other reasons. The repeatability check of the modeshape phase is also performed. The phase of the mode shape is different for different data sets. Therefore, the cause of the low accuracy mode shape identification is considered different from synchronization error.

3. Conclusion

The multihop communication scheme, Choco on Glossy, is implemented and applied to suspension bridge vibration monitoring. Choco on Glossy has desirable characteristics such as robust, no need of routing information, quick and fast to transfer data, taking advantage of the constructive interference phenomena. While the sensor networks were able to identify structural modes consistent with past research and reports in terms of their frequencies, the identified mode shapes showed non-smooth mode shapes. The phase of mode shapes are not necessarily close with that of lightly damped linear systems. The repeatability of mode shape identification was not high. The system and data are considered of poor quality with respect to mode shape identification. The system need to be further updated for wide-spread use in full-scale structure measurement.

References

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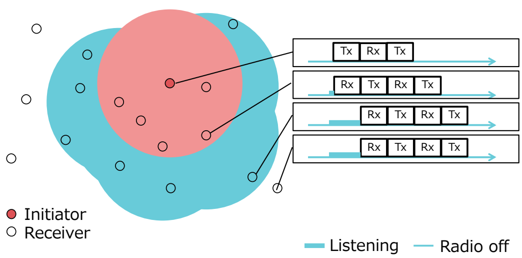

Fig. 1: Glossy overview [3]

Fig. 2: Wireless sensor nodes

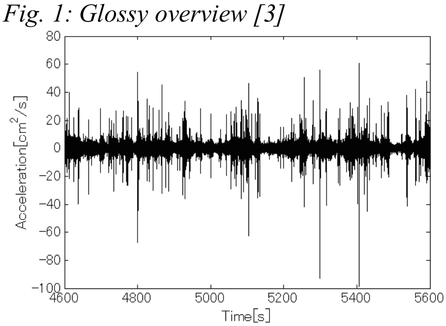

Fig. 3: Typical acceleration time history

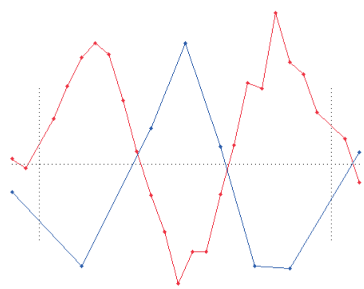

Fig. 4: Identfied torsional mode (1.06Hz)