Study on Real-time Bridge Bearing Displacement Monitoring Using IoT Devices

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1. INTRODUCTION

the Internet of Things (IoT) solution is expected to help to relieve the situation that there are not sufficiently experienced inspectors available while the demands for bridge maintenance management like regular inspection are rapidly increasing [1]. As a key member of bridge structures, the bearing functions to transmit various kinds of loads on bridges. Displacement of bridge bearings is the most direct factor to reflect the functional status of bridge bearings. This study proposed a low-cost IoT based real-time bridge bearing displacement system, the measurement unit of which meanly consists of a Raspberry Pi 3 Model B (RPi) single-board computer, AD/DA converter module for RPi, and a Keyence laser sensor IA-100. The measurement system was developed under Python open-source environment to handle data acquisition, data storage, and data transfer. Shaking table tests and on-site monitoring were conducted to verify the accuracy of the proposed method.

2. MEASUREMENT METHODOLOGY

The acquired data from sensors is processed by the RPi and then saved to local storage and uploaded to the cloud seamlessly. Real-time availability of data over the internet is an unprecedented advantage that IoT brings to us. Since the displacement of bridge bearings is just millimeter level under service status, the resolution of chosen sensor must be sub-millimeter level. Therefore, a laser sensor with high accuracy was used in the development. Figure. 1 shows the outline of the measurement method. Analog signal is converted to digital signal by the AD/DA converter module and then processed in the RPi.

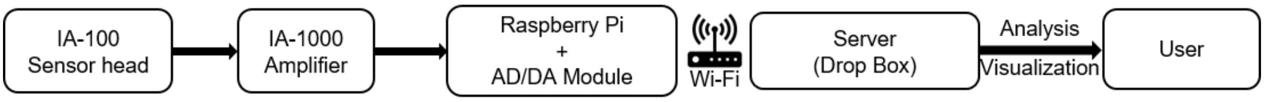


Figure 1. Outline of the proposed method

3. SHAKING TABLE TESTS

Shaking table tests were carried out on a uni-axis shaking table as shown in Figure 2. The laser sensors connected to RPi and reference data logger were IA-100 and IA-1000 respectively. The objective of the tests was to verify the performance of substituting the traditional data logger with the combination of RPi and AD/DA converter module. The sampling rate of both sides were set at 100 Hz. The vibrations were set as a matrix of frequency in the range of 0.1~10.0 Hz and amplitude in the range of 0.5~10.0 mm.

As the measurement results, the sampling rate was stable at 100 Hz. Two example cases are shown as in Figure 3, the resolution of proposed method was in sub-millimeter level as like the reference. And the waveforms of IoT devices agreed with of the reference very well. The results show that the IoT device did not miss any vibrations in the tests regardless the frequency and amplitude in the setting range.

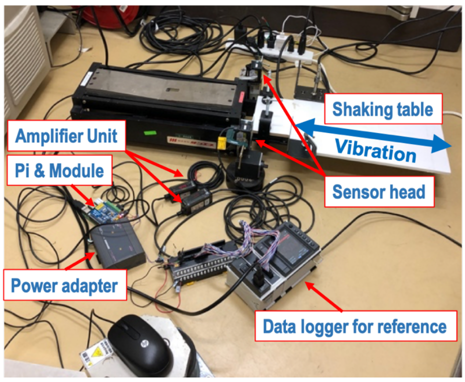
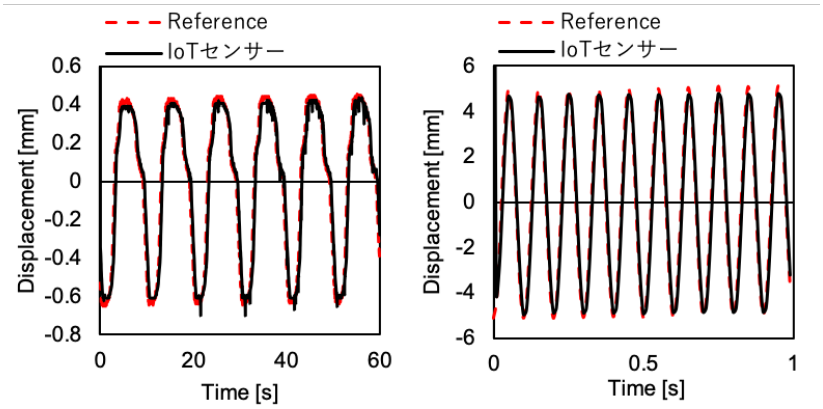


Figure 2. Shaking table tests setting.



(a) Frequency 0.1 Hz, amplitude 0.5 mm (b) Frequency 0.1 Hz, amplitude 0.5 mm

Figure 3. Waveform comparison

Keywords: Internet of Things (IoT), Bridge Bearing, Real-time Displacement Monitoring

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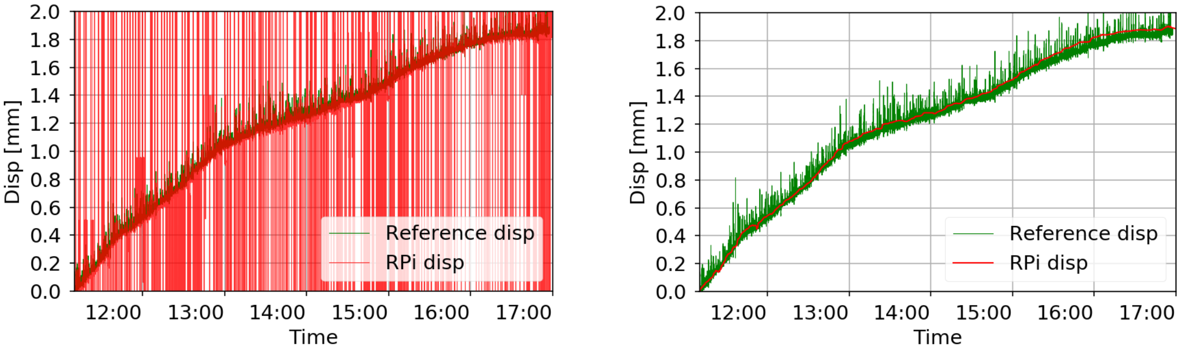
4. ON-SITE MEASUREMENTS

Thereafter, on-site bridge bearing displacement measurements were carried to verify the stability of the proposed measurement system in the real operation environment for long term. The measurement reference was the same as in the shaking table tests. The power and the Internet access of the IoT system were provided by a portable power bank and a pocket Wi-Fi respectively. The measurement lasted around 6 hours from 11 am to 5 pm, and the measurement target was the displacement of the upper bearing of one abutment in the longitudinal direction of a girder bridge as shown in Figure 4. The overall 6-hour raw data with sampling rate at 100 Hz is plotted in Figure 5-a, though the main trend lines are overlapped with each other, the noise of RPi is noticeable and the value of it is extreme. In Figure 5-b, A rolling window filter with median method is taken, it can be seen that the extreme value considered as noise is cut off. The filtered signal obtained from the IoT system was considered capable to represent the displacement behavior of the target in long term. As of the performance in short periods, two-minute data was truncated out as shown in Figure 6. The lines coincide well except for the time where the abnormal pulse appears. Therefore, the main issue to solve in order to satisfy the accuracy of both long-term and short-term requirement is the randomly occurred pulse in the digital signal.



(a) plot with raw data (b) plot with filtered data

Figure 5. Long-term performance comparison

Figure 4. Overview of the measurement target

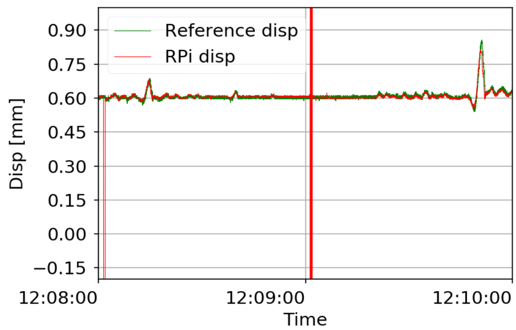


Figure 6. Short-term performance comparison

Additional tests for exploring factors affecting the occurrence of the signal pulse were carried out after the on-site experiment. The assumed factor was the supplement method of powering the IoT system. By a static test in which the variable was just the power supplement method, the occurrence rate of signal pulse for household power was 5.2×10^{-6}, which was 230 times smaller than that for pocket power bank. The stability of the power source was significant for the performance of converting the signal from analogue to digital.

5. CONCLUSIONS

This paper discussed the application of IoT devices on real-time bridge bearing displacement monitoring. Though the performance of the proposed system was sufficient in the shaking table tests, the unexpected pulse signal appeared when applying the proposed system on long-term on-site measurements. The obtained results of the on-site measurements showed that the proposed system was capable to represent the long-term behavior of the targeted bridge bearing. But in aspect of short-term behavior analysis, the pulse signal was unignorable, it was affected by the stability of the power source. The framework of the proposed system is applicable to real-time bridge bearing displacement tasks, and the performance of it is expected to be improved by more study on the stable power source for IoT devices.

REFERENCES

Ying Sun, Research on the Railroad Bridge Monitoring Platform Based on the Internet of Things. International Journal of Control and Automation, Vol. 7, No. 1 (2014) pp.401-408