TSINGHUA SCIENCE AND TECHNOLOGY
ISSN 1007-0214 36/67 pp223-227
Volume 13, Number S1, October 2008

Development of a Mobile Sensing Unit and Its Prototype Implementation*

Yusuke Mizuno**, Yozo Fujino†, Keita Kataoka‡, Yoshihiro Matsumoto††

Research Center for Environmental Safety, Yamaguchi University, Yamaguchi 755-8611, Japan;
† Department of Civil Engineering, The University of Tokyo, Tokyo 113-8656, Japan;
‡ Research and Development Center, East Japan Railway Company, Saitama 331-8513, Japan;
†† Kansai Electric Power Co., Inc., Osaka 530-8720, Japan

Abstract: This paper represents a design and development of a mobile sensing unit as well as its prototype implementation for railway track monitoring. The unit consists of an ultra-small personal computer (PC), a global positioning system (GPS) receiver, an accelerometer and an ADC (Analog/Digital Converter) so that the unit can trace the route while capturing an acceleration response of a passenger vehicle. The unit enables more frequent and qualitative data acquisition compared with traditional and the state of the practice railway track inspection equipments. Locating disorder is the key of our unit, which has a reasonable accuracy of positioning with GPS data, existing facilities landmarks, and car acceleration responses. The proposed unit is a promising device for efficient properties management of railway agencies. The prototype implementation shows a result that car acceleration responses are related with the track displacements in low frequencies. The results also imply that sensor settlement on a vehicle floor, not axes or bogies, is effective for capturing track vertical displacements.

Key words: mobile sensing; railway track monitoring; instrumentation; data acquisition; passenger vehicle; global positioning system (GPS)

Introduction

Railway track maintenance is a vital issue of satisfying commuters' demands as well as of reducing the risk of accidents. East Japan Railway Co. operates an inspection vehicle "East i-E" that investigates railway systems including electric power, signals, communication, and tracks[1]. In order to measure precise displacements of tracks, the measurement equipments are installed in the bogies. Due to the operating cost during the measurement, "East i-E" runs the same route in three months in low speed lines.

Railway tracks keep on progressing their displacements continually, especially after heavy rain sometimes brought by typhoons. A small earthquake may cause track displacement in Japan.

The objectives of the research are to develop a railway track monitoring system that enables more frequent measurements and make our system small and functionally enough to capture and locate disorders.

1 Instrumentation

1.1 Requirement analysis

A simple and low-cost monitoring system has been developed[2,3]. The results indicated that high correlation between train acceleration and track irregularity.

Received: 2008-05-30
* Supported by the joint research project between East Japan Railway Company and the University of Tokyo
** To whom correspondence should be addressed.
E-mail: mizuno@yamaguchi-u.ac.jp; Tel: 81-836-85-9532

However, their target field, Isumi line, was not good for global positioning system (GPS) surveying due to the mountainous environment. The equipments still need to be downsized.

The below shows the requirements of our prototype for railway track monitoring.

- Acceleration measurement
- Locating disorders
- Easy settlement in passengers' vehicle
    - Less cabling
    - Battery powered

The key element is to be installed in a passengers' vehicle, which means that the system can be settled as needed in order to increase a number of measurement trials. It also restricts the system to being self-enclosed so that the system may be installed in different type of train vehicles.

1.2 Components

The prototype of the mobile sensing system for railway tracks (ms4RAIL) is shown in Fig. 1. It consists of a three-axis accelerometer, ADC (Analog/Digital Converter), and an ultra portable personal computer (PC). The accelerometer adopted in this research is manufactured by Silicon Designs. It requires +5 V input and produces –4 to 4 V differential output, which corresponds −5 to 5 G (5×9.8 m/s^2) if Model 2422-005[4] is selected. The 2442-005 is sensitive to measure at the level of 10^{-3} G (10^{-2} m/s^2). The sensitivity is enough to detect acceleration responses induce by running vehicle on tracks. The ADC USB-6009[5] is manufactured by National Instruments, and has 14-bit resolution. The combination of these accelerometer and ADC requires only one USB cable for power supply and data acquisition. The PC VGN-UX50 is an ultra portable PC with enough capacity of operating Windows XP Professional. It has one USB port which is connected to the ADC, and wired and wireless LAN connections. The VGP-BGU1 is a GPS receiver manufactured by Sony, which connects a PC or other devices via Bluetooth.

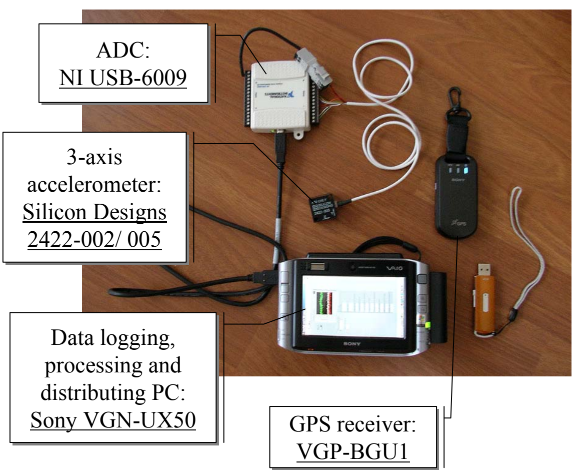

Fig. 1 Prototype implementation

NI LabVIEW[6] is installed in the PC and a small data acquisition program is developed in order to collect acceleration response to the PC's storage. LabVIEW offers very easy and user friendly interface so that undergraduate students can make their own program quickly.

1.3 Settlement

The prototyped mobile sensing unit is installed in the cockpit of the first vehicle so that it avoids passengers' footsteps. Figure 2 and 3 show the detail settlements of a sensing unit and a GPS receiver, respectively.

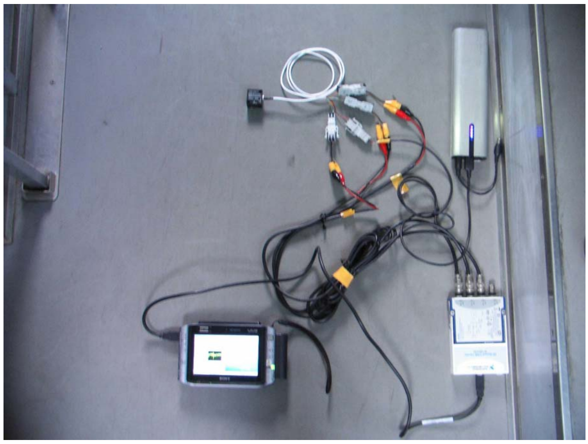

Fig. 2 Sensor unit settlement

Fig. 3 GPS receiver settlement

2 Data Acquisition

2.1 Field measurement

The target line is a typical commuter line connecting between suburban and urban areas in Tokyo area. The field measurement was carried out on 24th April, 2007 and it usually takes an hour in one direction. In the rest of the paper, data acquired between Station "A" and Station "B" are discussed mainly for the proof of our concept.

2.2 Locating a vehicle

The GPS receiver sends National Marine Electronics Association (NMEA)[7] sentence every second. The format recommended minimum specific GPS/transit data ($GPRMC) is captured and the latitude and longitude data is converted to local x-y coordinates. The distance between "A" and "B" stations is 6566 meters when calculated based on GPS data; however, the actual distance is 5434 meters as noted in the track profile.

The locating error is about 20% of original track distance. The error has been occurred due to the loss of the GPS satellite data when passing through viaducts and stations. It is shown that the data when train vehicles starting and stopping around station is not very stable. The error is distributed to each GPS positioning points in order to compensate the distance. Figure 4 illustrates the compensated distance.

2.3 Acceleration response

Due to the aliasing noises generated by radio transmission between train vehicles and the central control center and other electro-magnetic noises, the ADC was changed to NI USB-9233[8] that has variable anti-aliasing filters. The acceleration responses of a vehicle are measured with 2000 Hz sampling. Longitude, lateral, and vertical acceleration components are measured by a three-axis accelerometer mentioned above.

Although the vertical and lateral elements of acceleration are critical for the safety issues such as derailing, and are important for the comfortability of passengers. Only the vertical components of acceleration and displacement, described in the next chapter, are investigated in the rest of the paper for the proof of our concept.

3 Displacement-Acceleration

3.1 Measured Displacements

The East i-E measures displacement of railway track. The displacement has five components: gauge, level, vertical, horizontal, and plane geometry. The displacements were measured on 25th April, 2007. As mentioned above, the vertical component of displacement is examined.

The vertical displacements are consists of a pair of rails. The correlation between the displacements of two rails is relatively good since the correlation coefficient is equal to 0.87. The average of displacements of both rails is computed as an index of vertical displacement.

The displacement is measured an interval of one meter. The distance-displacement relation is translated to the time-displacement relation by using the time-distance relationship described in Fig. 4.

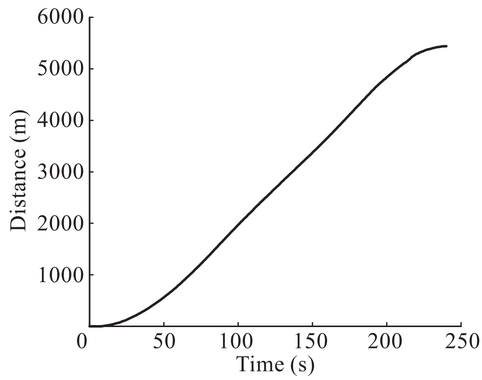

Fig. 4 Time-distance

3.2 Frequency analysis

Figures 5 and 6 show the vertical acceleration response and displacement respectively. Figures 7 and 8 are power spectra of acceleration and displacement respectively. As shown in Fig. 8, the components, which are greater than 20 Hz, are negligible small compared to low-frequency components. The frequency distribution of displacement stems from the measurement method applied to East i-E.

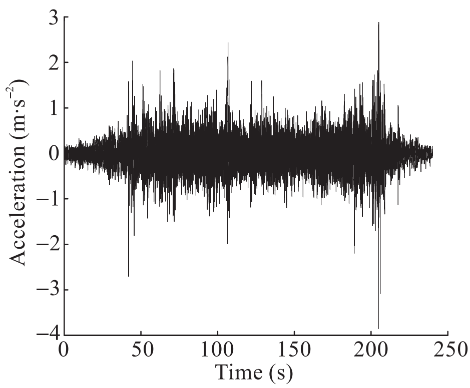

Fig. 5 Acceleration response

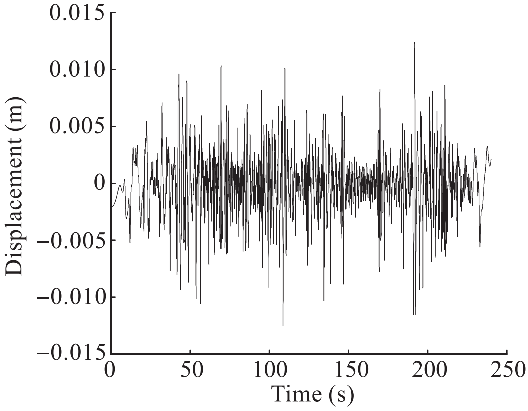

Fig. 6 Displacement time history

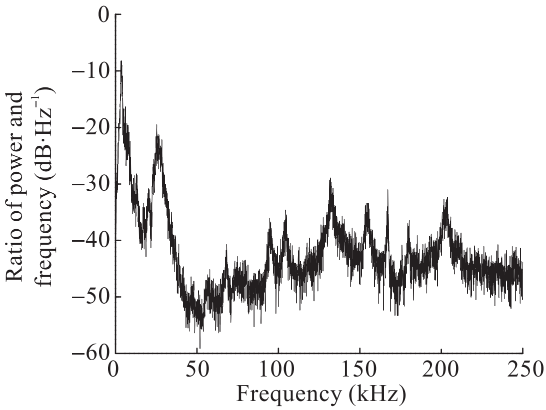

Fig. 7 PSD of acceleration response

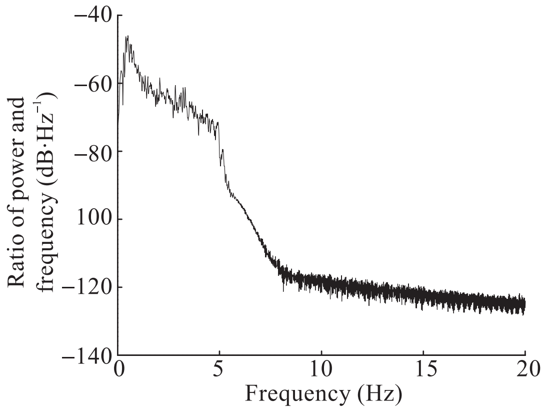

Fig. 8 PSD of displacement

Figure 7 describes that the components, which are greater than 20 Hz, still have some power. However, the high frequency components are not observed in Fig. 8, which indicates that the high frequency components are generated by train vehicle's equipments.

Figures 9 and 10 illustrate the wavelet coefficients of the acceleration response and the displacement. A vertical axis is shown by the shift parameter *b*, which can be converted to time and a vertical axis is described the scale parameter *a*, which can be converted to frequency. Figures 9 and 10 describe frequency-time responses. Pseudo-frequencies of acceleration and displacement are derived from the below equation:

$$f = \frac{F_c}{a \cdot \mathrm{d}t} \tag{1}$$

where *a* is a scale parameter in a vertical axis, F_c is a specific value depending on a mother wavelet. In this research, Morlet wavelet is chosen, and $F_c = 0.8125$. $\mathrm{d}t$ is a sampling period. Since a mother wavelet usually has a dominant frequency band in frequency domain, not a specific number, the word "pseudo-frequency" was shown above. However, the band is very narrow so that the word "frequency" may be used for a mother wavelet dominant wave component.

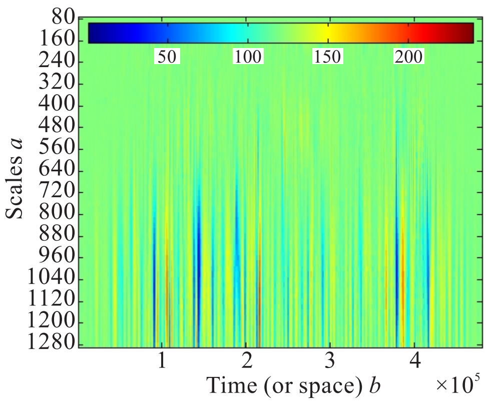

Fig. 9 Wavelet coefficients of acceleration

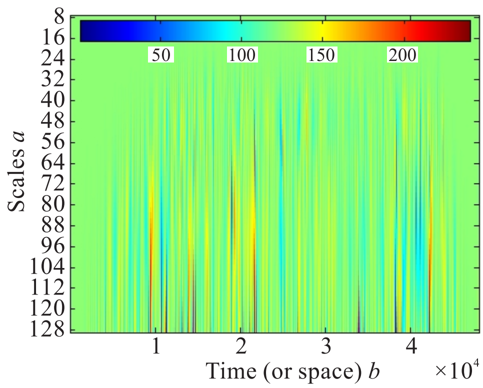

Fig. 10 Wavelet coefficient of displacement

The horizontal axis are converted the following Equation:

$$t = b \cdot \mathrm{d}t \tag{2}$$

where *b* shows a shift parameter in a horizontal axis.

$\mathrm{d}t$ values in Figs. 9 and 10 are equal to 0.0005 and 0.005 seconds, respectively. Scale *b* values of 1×10^5

and 1×10^4 in Figs. 9 and 10 correspond to time of 50 seconds, respectively. In the same way, scale *a* values of 800 and 80 in Figs. 9 and 10 correspond to frequency of 2.031 Hz, respectively. It is indicated that acceleration response of a vehicle shows promising index for describing rail track vertical displacements. The similar trends are found in Figs. 9 and 10. From 50 to 100 seconds, and around 200 seconds, the coefficient intensities are relatively large in the both figures, as amplitudes of Figs. 5 and 6 are large. The corresponding frequency band is between 1.354 Hz (*a* values of 1200 and 120 in Figs. 9 and 10, respectively) and 2.031 Hz (*a* values of 800 and 80 in Figs. 9 and 10, respectively).

4 Conclusions and Future Work

The prototype of a mobile sensing unit for railway track (ms4RAIL) has been developed. It enables more frequent track monitoring compared to the conventional method. It also indicates the possibility of instrumentation for a number of passenger vehicles. As the proof of the concept, vertical acceleration response and the displacement are examined. The results showed a good performance of measuring method proposed in this research. It may indicate that the acceleration response on the floor of a passenger vehicle is a promising index to capture railway track disorders in vertical direction.

The further enhancements are to investigate the longitudinal and lateral components of acceleration response, and accumulate field measurement cases.

References

[1] Takagi T. East Railway Co., E491 series electricity and track general inspection car bogie "Easti-E." *Tokyu Car Technical Review*, 2002, **52**: 68-71. (in Japanese)

[2] Fujino Y. A study of train intelligent measurement system using acceleration of train. Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems. *Proceedings of SPIE*, 2007, **6529**(65291H).

[3] Ishii H, Fujino Y, Mizuno Y, Kaito K. A development of train intelligent monitoring system using acceleration of train. *J. of Construction Engineering and Management, Japan Society of Civil Engineers*, Division F, 2008, **64(**1): 44-61. (in Japanese)

[4] Silicon Designs. Accelerometer Product Listing, http://www. silicondesigns.com/Prod.html.

[5] National Instruments, NI USB-6009, http://sine.ni.com/nips/cds/view/p/lang/en/nid/14605.

[6] National Instruments, NI LabVIEW, http://www.ni.com/labview/.

[7] National Marine Electronics Association, http://www.nmea.org/.

[8] National Instruments, NI USB-9233, http://sine.ni.com/nips/cds/view/p/lang/en/nid/202100.