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Relationship between train vibration and track irregularity for condition-based track maintenance

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Abstract

Up to now maintenance of railway tracks is conducted mainly based on the track irregularity data measured by track inspection vehicles and/or specialized measurement apparatus. The vibration data of running trains are easy to measure and can be the base of track maintenance, but they have not been used by the basic data of track maintenance because of the shortage of constancy of values. As the special inspection vehicles and apparatus are expensive, it becomes hard to maintain the tracks in regional railway lines and it is keenly desired to develop the economic procedure of track maintenance in local railway lines. Therefore, the authors tried to construct the method for track management based on train vibration data measured by permanently installed small IOT devices on in-service trains with high frequency. After the development of some new data processing methods, especially to obtain accurate positioning data of the trains from GPS speed data, very high constancy of train vibration data has been achieved and verified the relationship between train vibration and track irregularity, which is enough to use track maintenance. In this way, the authors successfully verified the possibility of the "train-vibration-based track maintenance".

Keywords: condition monitoring, track maintenance, IoT device, GPS.

1 Introduction

Currently, the maintenance of railway tracks is carried out based on track irregularity measurement data. The vibration data of running trains are easy to measure and can be related to the track irregularity, but they have been used only by the supplementary data of track maintenance because of the shortage of constancy of values [1]. However, there are an increasing number of cases where small portable information terminals, so-called "smartphones" with MEMs, are used as simple and inexpensive vehicle vibration measuring devices [2][3]. Therefore, the authors tried to develop the method for track management based on the train vibration data measured by permanently installed small terminals on in-service trains with high frequency.

2 Methods

2.1 Train vibration monitoring by in-service trains

A small mobile device, SMD, (94x58x16mm, 102g) has been set on the driver cab permanently and measured the vibration and angle movements of 3-axle directions. In order to consider the relationship between train vibration and track irregularity, the authors took the relationship of vertical acceleration and track level irregularity first. After the verification of the accuracy of SMD for measurement devices by comparison with a high-spec measuring instrument, the long-term running experiment was started on a local railway line.

2.2 Compensation of GPS speed for accurate train running position [4]

For the management of the tracks using train vibration the identification of train running position is very important because it is essential to grasp the track position for measured train vibration. To decide the position by using the speed information from GPS, i.e., "GPS speed", is relatively easy, but in the case of the multi-path occurrence, the accuracy of positioning is remarkably decreased.

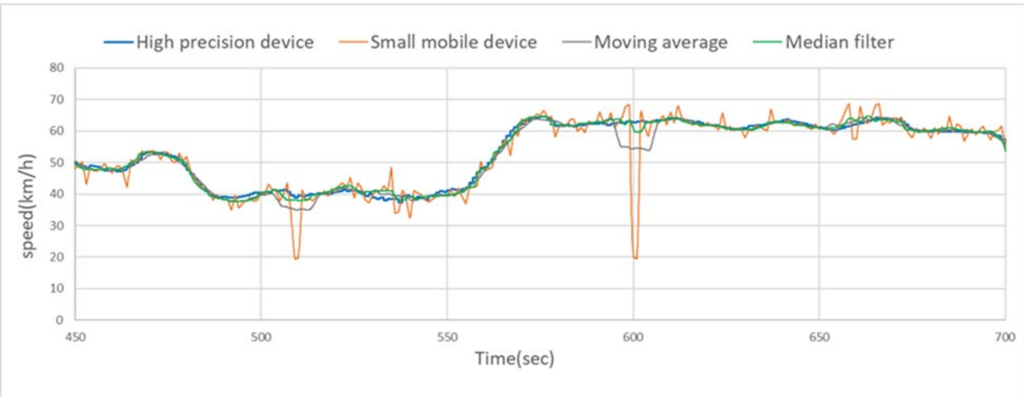

Figure 1: Train speed change measured by GPS speed including multi-path error and compensation

Figure 1 shows the case of multi-path occurrence. The train speed drops were caused by errors of GPS speed signal around 510sec and 600sec. The train position cannot be correctly calculated after them, and compensation is necessary. “Method 1”; using “moving average” is not sufficiently corrected, on the contrary, “Method 2”; using “median filter” is correctly compensated as shown in the figure.

2.3 Compensation by waveform matching with track irregularity

The compensation using the median filter is good, but in order to get higher constancy, the additional compensation uses the waveform matching with basic track irregularity data. In this railway, the track precise measurement by the track inspection car has been annually provided. So, using these data, the waveform matching “train vertical vibration fluctuation wave” with “track irregularity fluctuation wave” produces a more accurate train position, and realizes a very high constancy of train vibration as shown in Figure 2.

2.4 Constancy of measured train vibration data

The train vertical vibration data measured on in-service trains for 12 months are shown in Figure 2. The measured data of each month agree very well together at every track position along the track. This figure shows the very high constancy of train vertical vibration data, which are enough for the basic data of the maintenance of longitudinal track level irregularity.

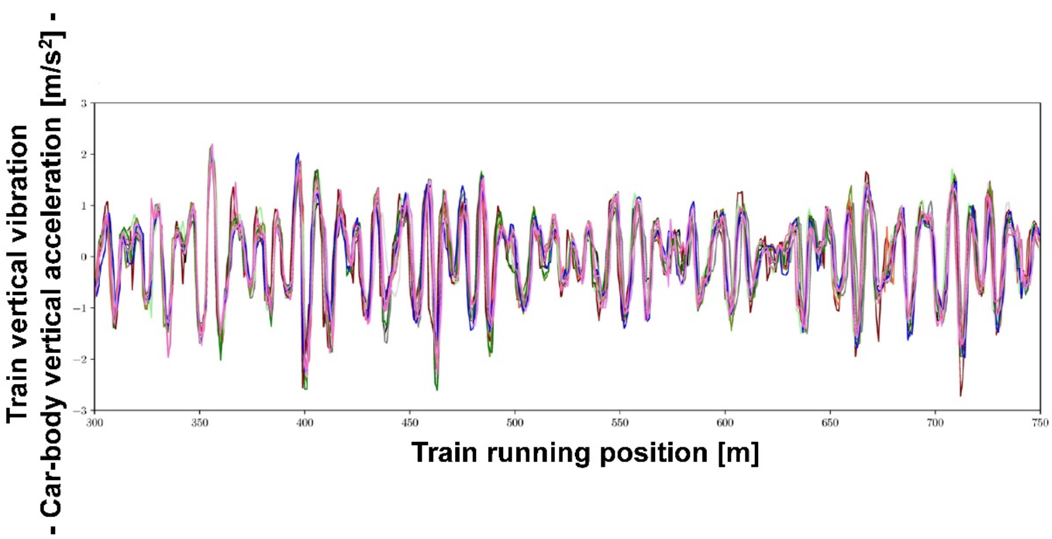

Figure 2: Train vertical vibration fluctuations along track for 12 months.

3 Results

3.1 Relationship between train vibration and track irregularity

The train vertical vibration is related to track vertical irregularity because vehicles are excited by track displacements [5]. Figure 3 shows the scatter plot figure of “train vertical vibration, i.e. car-body vertical acceleration" vs. "track longitudinal level irregularity" that have been measured on many in-service trains on a local railway line. Both values are strongly correlated, so the longitudinal vertical track irregularities can be estimated by the train vibration data.

3.2 Check of track maintenance effects and estimation of track deteriorations in the future

The effects of track maintenance work in some sections may be confirmed from the daily measurement of in-service trains. On the contrary, the future deteriorations of track sections can be estimated by the regression analysis from the past data of each section.

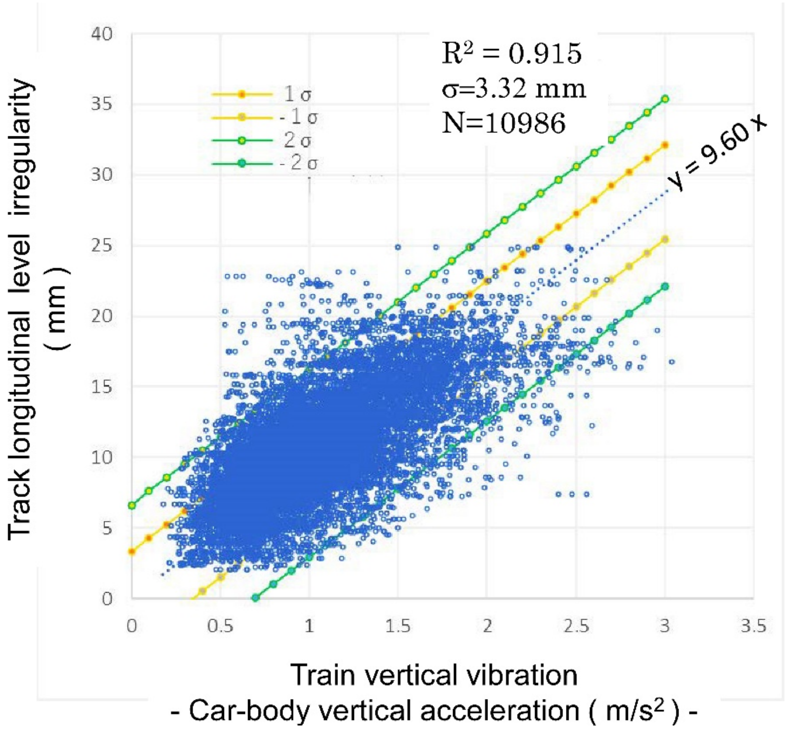

Figure 3: Relationship between train vertical vibration and track longitudinal level irregularity.

4 Conclusions and Contributions

As the results of data accumulation of car-body vertical acceleration data of in-service trains for more than one year on a local railway line, and considerations on data processing, the authors successfully conclude the possibility of the "train-vibration-based track maintenance".

The conclusions of the study are as follows;

(1) The compensation against multi-path errors by using the median filter provides the accurate train running position from GPS speed data.

(2) The additional compensation by wave matching with basic track irregularity data which have been measured annually provides the more accurate train position and realizes a very high constancy of train vibration for track maintenance.
(3) The measured big data of train vertical vibrations and track longitudinal level irregularities have the high correlation, and track irregularities can be estimated by measured car-body vertical acceleration of in-service trains.
(4) Daily measurement of the train vibration can check and estimate the deterioration of railway tracks.
(5) The track management method based on the measurement of in-service train vibration is proposed, and the procedure is shown in Figure 4.

For further study, the authors try to examine the track maintenance of other irregularities, such as “alignment”, “level”, etc.

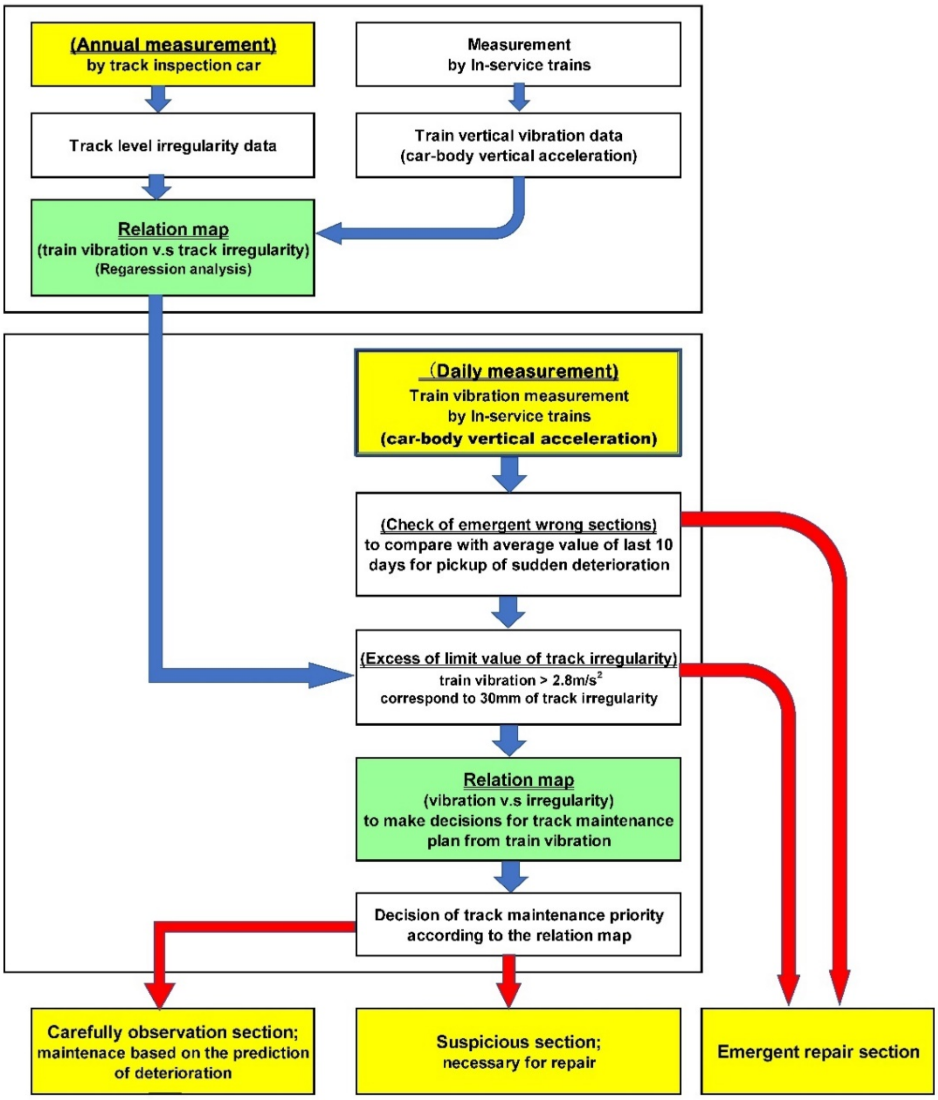

Figure 4: Track management based on daily measurement of in-service train vibrations

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