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Track continuous monitoring using vehicle dynamic measurements from the commercial fleet

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Abstract

In this paper, a methodology for continuous monitoring of railway track geometry based on acceleration measurements from commercial trains is presented. A strict correlation between track longitudinal level and bogie vertical acceleration was identified making use of synthetic indicators. A linear regression model relating the standard deviation of the track geometry to the RMS of the bogie vertical acceleration was realized. The combined use of vehicle dynamic data and the proposed linear model allowed to accurately estimate the longitudinal level in a specific section of the rail line. The described results represent a first step towards the development of methodologies for track condition-based maintenance relying on measurements coming from the commercial fleet.

Keywords: Condition-based maintenance, rail vehicle dynamics, track longitudinal level, in service vehicle

1 Introduction

Monitoring of track geometry, and more in general of the railway infrastructure, is usually performed by dedicated diagnostic vehicles, equipped with suitable measuring systems [1], that regularly run on the different lines of the network.
On account of the limited number of diagnostic vehicles, due to the significant costs related with their set-up, operation and maintenance, and of the extension of the network, the information about the track status is available only periodically.

On the other hand, commercial vehicles travel on the lines at least on a daily basis and modern vehicles are equipped with measuring devices (usually accelerometers) for vehicle diagnostic purposes. Since the track geometry directly affects the dynamic behaviour of the vehicle, the available measurements, if properly treated, could be usefully adopted also to set a continuous monitoring of the railway track/infrastructure status.
With this respect, some authors considered the possibility to directly estimate the track irregularity input from the vehicle response, adopting different approaches [2-4]. Model-based solutions were designed to identify track irregularity by solving inverse problems. To this end, Kalman filter [5] and wavelet transform [6] are well known algorithms.
However, all these methodologies still rely on the adoption of dedicated measurement systems, provided with numerous sensors such as accelerometers and gyroscopes.
In this paper the possibility to adopt synthetic values extracted from vehicle dynamics to continuously monitor the track quality, with particular reference to the longitudinal level that describes vertical irregularity, is investigated. The final aim is to set continuous monitoring procedures based on measurements coming from the commercial fleet.

2 Methods

In order to verify the possibility of track continuous monitoring using vehicle dynamic measurements, it is important to assess the level of correlation between track geometry and vehicle dynamic quantities.
Different track quality indexes can be defined [7]: the standard deviation of track geometry parameters or the number of isolated defects exceeding a certain threshold are typically used. In this analysis, the attention was focused on the longitudinal level that describes the vertical irregularity of the track. The standard deviation of the longitudinal level in the D1 range [8], computed on a 100 m window, was compared to the vertical acceleration of the bogie. The bogie, in fact, is typically responsive to the excitation introduced in the D1 wavelength range. The information of the acceleration signal is condensed in the RMS value computed along the same window of the standard deviation of the longitudinal level.
Figure 1 shows on the top subfigure the standard deviation of the longitudinal level in the D1 range and on the bottom the RMS of bogie vertical acceleration. The values are computed along a 14 km long track section.

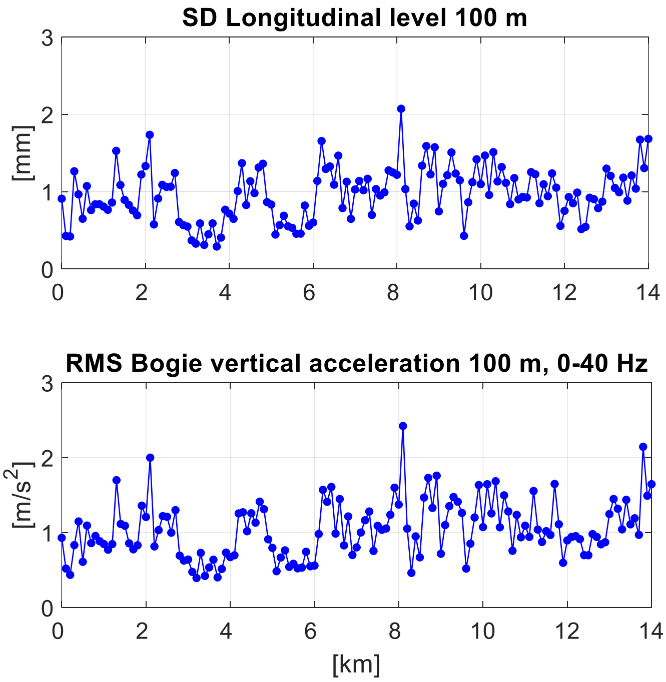

Figure 1: Standard deviation of the longitudinal level in the D1 range (top) and RMS of bogie vertical acceleration (bottom) on a 14 km long track section.

A strong degree of correlation can be registered when comparing the two indicators at the same milestone position. Being the trends of the two lines very similar, they suggest the possibility of estimating track quality using simple vehicle dynamic measurements. In this respect, Figure 2 shows the scatter plot of the two just defined quantities. Each point on the diagram represents a track section of 100 m. A linear model relating the two indicators was computed, and the best fitting line is also shown as a continuous line. It is observed that the dispersion of the data along the regression line is limited, and this is also confirmed by the value of the coefficient of determination R^2 that is equal to 0.932.

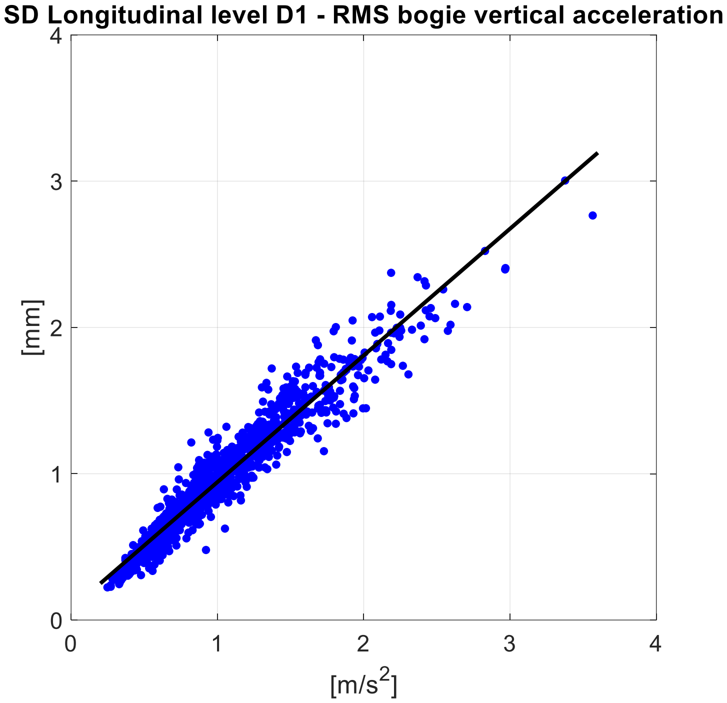

Figure 2: Standard deviation of the longitudinal level in the D1 range and RMS of bogie vertical acceleration along a 100 m window (regression line in continuous line).

Thus, the standard deviation of the longitudinal level in the range D1 can be estimated with a good accuracy by means of the RMS of the bogie vertical acceleration.
This outcome poses the basis for the exploitability of the methodology: the RMS of the bogie vertical acceleration computed by in service vehicle can be adopted to provide a daily estimate of the track quality.

3 Results

The linear model of Figure 2 is tested considering the evolution of the standard deviation of the longitudinal level in a specific 100 m window of the considered track. In Figure 3, the diagrams on the left show km 5-8 of Figure 1 in terms of standard deviation of the longitudinal level (top left) and RMS of bogie vertical acceleration (bottom left). Compared to Figure 1, each coloured line refers to a different train run recorded in a period of 20 months.
Focusing the attention on km 6.6 (highlighted by a red dashed box), the diagram on the right shows the evolution with time of the standard deviation of the longitudinal level. Circle markers refer to the index computed from the direct measure, whereas star markers represent the estimation implying the RMS of the bogie vertical acceleration and the linear model of Figure 2.

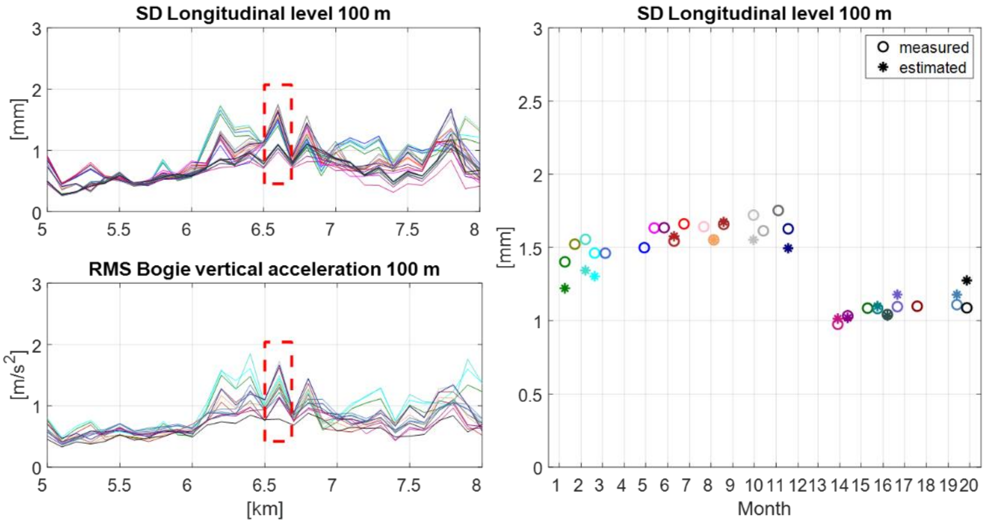

Figure 3: Results of the methodology application. On the top left, measured standard deviation of longitudinal level; on the bottom left, RMS of bogie vertical acceleration; on the right, estimation of the standard deviation of longitudinal level adopting vehicle dynamics data.

The track geometry estimation from acceleration data turns out to accurate. Despite minor under/overestimations, the evolution trend is indeed correctly traced both before and after track renewal (month 12). Notice that an estimate was computed for comparable vehicle speed, being the RMS of the vertical acceleration dependent on it. This is the reason why a lower number of star markers can be observed on the right diagram. Nevertheless, when available, also the quantitative estimate of the track geometry turns out to be satisfactory, with a maximum error of about 0.2 mm.
The methodology can be applied in any position of the railway line, providing similar results in terms of accuracy in the evolution prediction. These results demonstrate the possibility to continuously monitor track condition by means of vehicle dynamic measurements.

4 Conclusions and Contributions

In this paper the possibility of continuous monitoring of track geometry using vehicle dynamic measurements from fleet have been investigated. It was proven that a high correlation exists between track quality indexes and synthetic values obtained from dynamic measurements available on trains used for commercial service.
In particular, the attention was focused on the longitudinal level in the D1 range (3-25 m). It was proven that the standard deviation of this parameter, computed along a 100 m window, is highly correlated to the RMS value of the vertical acceleration of the bogie. This opens the possibility of using this synthetic parameter for the continuous monitoring of track geometry.

A linear model relating these indicators was realized and adopted to estimate the longitudinal level from acceleration data. The preliminary results provide accurate estimations of the track condition and allow tracing the trend evolution over time.
Modern commercial trains can be equipped with accelerometers on the bogie for implementing the diagnostics and the condition-based maintenance of the vehicle. The signal from the same sensor, processed in a proper way so to compute the RMS value on a 100 m window, can be also used for track monitoring, with a huge advantage compared to the adoption of a single track recording vehicle. Commercial trains are running with a high frequency on the railway lines and, if each bogie is instrumented, data can be collected each day, making the analysis very robust. Thus, the evolution of track geometry can be followed more frequently eventually permitting to schedule maintenance operations when needed.

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