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Vehicle response prediction to detect hidden anomalies in track geometry degradation

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Abstract

The assessment of track geometry degradation plays an important role for maintenance planning. State-of-the-art methods for assessment are commonly based on maximum and standard deviation values. A problem of analysing track degradation only by this pure geometry features is that possible occurrences of 'hidden anomalies' are missed. Hidden anomalies are defined in this paper as special track geometry shape patterns that cause unexpected vehicle responses under certain operating conditions.
This paper describes a method to detect hidden anomalies in track geometry degradation by consideration of vehicle responses. In the first step, Multi Body Dynamics (MBD) simulation scenarios are carried out for different vehicle types, vehicle speeds, vehicle loading conditions and different wheel/rail friction conditions. The excitations are a combination of the real track layout and a set of historical track geometry irregularities. Virtual sensors measure wheel/rail forces as well as axle box, bogie and carbody accelerations.
In the next step, time series data of each virtual sensor obtained by the simulation results are used to assess the 'current' response of the 'current' measured track geometry. Therefore, the track is divided into 200 m sections and the maximum values as well as the standard deviation values of the vehicle response forces and accelerations are calculated. For each virtual sensor, a linear regression model based on the historical responses is calculated. To assess the 'current track geometry', each vehicle response value (resulting of the current track geometry irregularities) is compared with its 95% prediction interval. A value outside the prediction interval means that the vehicle response value is not expected due to the historical track

geometry degradation. For an overall assessment of the 'current track geometry', the expectation values of all sensors are statistically combined to a final expectation value for a hidden anomaly.
To compare the proposed method with state-of-the-art methods, artificial anomalies are superposed to the real measured track geometry. In almost every section, these hidden anomalies cannot be detected by analysing only the pure geometry degradation behaviour. In contrast, the proposed method of this paper shows unexpected values for almost every section. This comparison emphasizes the high potential of the proposed method to detect hidden anomalies in track geometry measurement data.

Keywords: anomaly detection, track geometry degradation, vehicle-track interaction, maintenance decision basis, track geometry assessment.

1 Introduction

Track geometry plays an important role for the interaction between the vehicle and track. To ensure safety and comfort of running vehicles, track geometry is measured every second month and the quality is assessed according to the European Standard EN13848 'Track geometry quality' [1]. The standard defines a set of track geometry features, e.g. maximum and standard deviation values. Based on these features, the degradation behaviour of the track can be evaluated, and maintenance can be effectively planned using time series prediction.

A problem of analysing track degradation only by geometry features is that possible occurrences of 'hidden anomalies' are missed. Hidden anomalies are defined in this paper as special track geometry shape patterns that cause unexpected vehicle responses under certain operating conditions. Operating conditions are for example the vehicle speed, loading conditions as well as friction conditions between the wheel and rail.

The aim is to find such hidden anomalies in track geometry data using vehicle responses. There is previous research on assessing track geometry irregularities by taking into account vehicle response forces [2, 3]. In most cases, these methods are very simplified to fulfil practical application requirements and neglect the different operating conditions. Furthermore, they only assess the current track geometry and do not consider historical measurement data to decide if these responses are expected or not.

2 Methods

This paper describes a method to detect hidden anomalies in track geometry degradation by consideration of vehicle responses. In the first step, the vehicle responses are obtained by the use of several Multi Body Dynamics (MBD) simulations. MBD simulation scenarios are carried out for different vehicle types, vehicle speeds, vehicle loading conditions and different wheel/rail friction conditions. The excitations are a combination of the real track layout (straight, transitions and curved track elements) and a set of historical track geometry irregularities. Virtual sensors measure wheel/rail forces as well as axle box, bogie and carbody accelerations.

In the next step, time series data of each virtual sensor obtained by the simulation results are used to assess the 'current' response of the 'current' measured track geometry. Therefore, the track is divided into 200 m sections and the maximum values as well as the standard deviation values of the vehicle response forces and accelerations are calculated. For each virtual sensor, a linear regression model based on the historical responses is calculated. To assess the 'current track geometry', each vehicle response value (resulting of the current track geometry irregularities) is compared with its 95% prediction interval. A value outside the prediction interval means that the vehicle response value is not expected due to the historical track geometry degradation. Figure 1 illustrates the calculation of such an expectation feature by the ratio of the deviation 'a' of the current response value from the expected value (blue line) and the half of the 95% prediction interval 'b'. A ratio value a/b greater than one (as shown in Figure 1) means that this response is not expected. For an overall assessment of the 'current track geometry', the expectation values of all sensors are statistically combined to a final expectation value for a hidden anomaly.

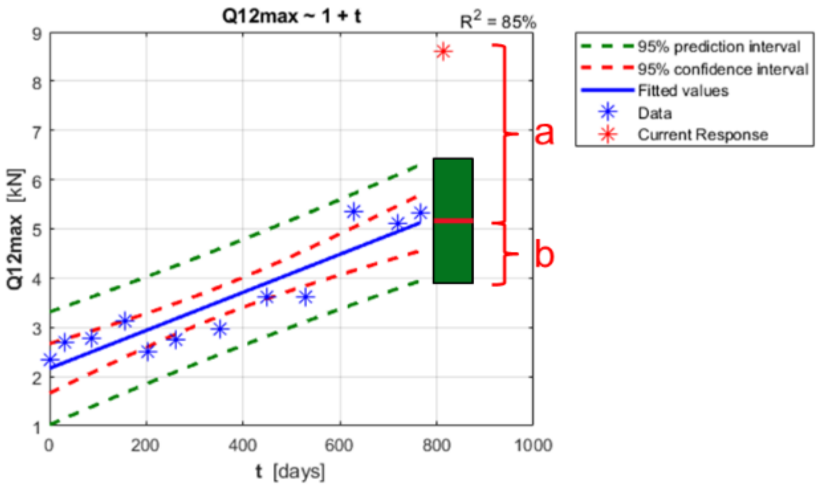

Figure 1: Time series prediction to calculate the expectation value

3 Results

As a case study, thirteen data sets of historical track geometry measurement campaigns between 02/2016 and 05/2018 from the Swedish network were analysed. Several MBD simulations with this track geometry data were carried out with two vehicles (locomotive and passenger coach) for different operating conditions. The first 12 historical data points of each virtual sensor are used to generate linear regression models. The predicted values of each sensor are compared with the MBD simulation results of the 'current measurement' which is in this case the measurement number 13. As an example, the results for the virtual sensor 'lateral wheel force Y11' of a locomotive are presented in the third row in Figure 2. Most sections show expected values and some sections show unexpected values highlighted in red. To compare the proposed method with state-of-the-art methods, the same approach is used for pure track geometry data - as represented by the track alignment of the right rail shown in the fourth row in Figure 2. Here it can also be seen that most sections show an expected track geometry degradation behaviour.

Due to the lack of information about 'real hidden anomalies', artificial anomalies (in this case a sinusoidal function in lateral direction) are superposed to the real measured track geometry. In almost every section, these hidden anomalies cannot be detected by analysing only the pure geometry degradation behaviour which can be seen in the second row in Figure 2. In contrast, the proposed method of this paper shows unexpected values for almost every section - see first row of Figure 2. A more detailed analysis of the track geometry and the vehicle response forces of section 5 along the track are shown in Figure 2 as well.

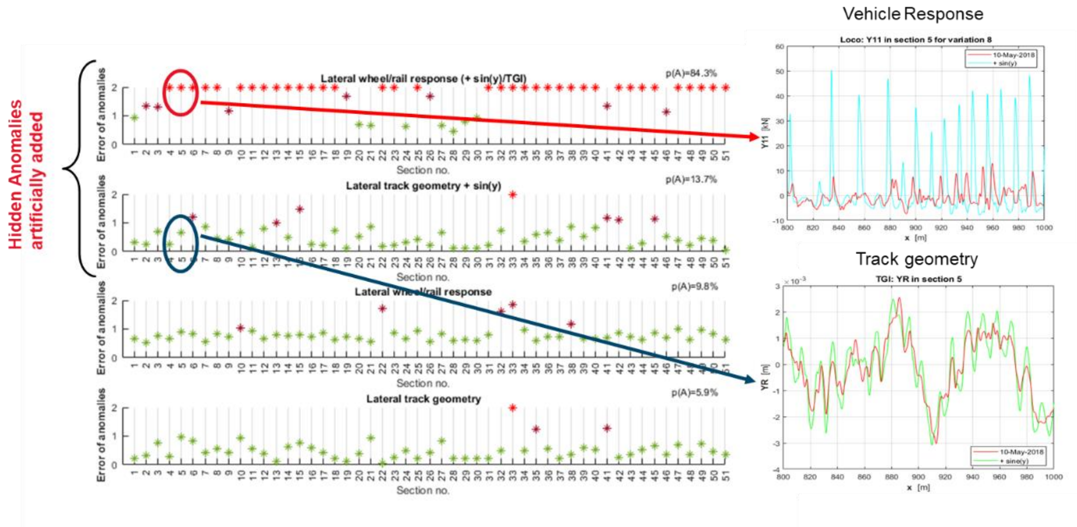

Figure 2: Expectation values for different 200 m sections along the track with and without artificially added hidden anomalies

4 Conclusions and Contributions

The results show the high potential of the proposed method to detect hidden anomalies in track geometry measurement data. The interaction between the vehicle and the track under several operating conditions is considered by introducing virtual vehicle response sensors. The sensor values are used for time series prediction of the vehicle responses. The comparison of the predicted vehicle response values and the simulated values for the current measured track geometry enables the detection of hidden anomalies.

The application of this method should be considered as an additional method to current state-of-the-art methods for assessing the track geometry (e.g. EN13848-5 and EN13848-6). The shown example of design parameter combinations can be extended to further vehicles and operating conditions if desired to cover a wider range of scenarios. In follow up steps, the method should be verified with track geometry data with known unexpected vehicle responses and could be adapted if necessary.

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References

[1] EN 13848-5 Track geometry quality - Part 5: Geometric quality levels, CEN, 2017.

[2] B. Luber, A. Haigermoser, and G. Grabner, “Track geometry evaluation method based on vehicle response prediction,” Vehicle System Dynamics, vol. 48, no. 1, pp. 157–173, 2010.

[3] A. Haigermoser, B. Luber, J. Rauh, and G. Graefe, “Road and track irregularities: measurement, assessment and simulation,” Vehicle System Dynamics, vol. 53, no. 7, SI, pp. 878–957, 2015.