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Continuous monitoring of rail vehicle dynamics by means of acceleration measurements

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Abstract

The increased demand for rail transportation requires continuous monitoring of both railway lines and vehicle dynamics for different reasons, ranging from system safety and reliability to effective management of maintenance interventions.
The target of the article is that of proposing innovative methodologies for data processing and analysis of experimental signals collected onboard, during long-term monitoring of in-service vehicles. The proposed methodologies are suitable for various rail transportation systems, ranging from metro to main line.
At first, a positioning algorithm is proposed to associate all the measured acceleration signals to the corresponding track sections where they were acquired. It consists in a map-matching procedure to project the GPS positions, stored by the train during commercial service, onto the digital map of the railway line. Once completed, synthetic indexes representative of vehicle dynamics performances, such as RMS acceleration values, can be computed and matched to their exact position along the track, allowing to investigate vehicle dynamics evolution both in time and with respect to the position along the railway line.
Two different data analysis approaches are proposed: the first one concentrates on the evolution of indexes and investigates how the train running dynamics changes with time, as a consequence of wheel/rail profile wear and track irregularity degradation; the second analysis relates the vehicle dynamics to local phenomena along the line and to the evolution of track maintenance conditions. One of the main outcomes of the proposed methodology is the possibility of continuously monitoring track quality

and of identifying critical sections along the line that may potentially need to be inspected, to decide whether dedicated maintenance actions are necessary.

Keywords: Condition-based maintenance, rail vehicle dynamics, railway infrastructure, onboard measurement.

1 Introduction

Rail transportation is becoming a key-player in the European mobility policies. Being at the onset of its limit capacity, to guarantee high level of safety, reliability and ride comfort for passengers, maintenance operations of both rail vehicles and infrastructure are of fundamental importance.

In the past, maintenance operations were scheduled according to designers' experience, with advantages in terms of planning easiness and even distribution of costs. Nowadays more reliable and accurate tools for predicting wheel wear evolution and wheelset lifetime should be considered, so as to achieve economical and safety benefits [1]. Furthermore, the increased demand for railway transportation is reducing the time available to carry out the inspections. As a result, Condition-Based Maintenance (CBM) is becoming a preferable choice for railway industry stakeholders.

Regarding CBM, which relies on real time data to prioritize and optimize maintenance resources, a distinction can be made between model-based and signal-based techniques. The former ones are typically used to estimate vehicle dynamics when there is no direct measurement of parameters, but there is access to the relationship between input and output signals [2]. Examples of model-based techniques relying on Kalman filter, observer-based methods and multi-model approach are provided in [3][4]. Signal based techniques are relevant, on the other hand, especially in case only the output signal is available. The main signal processing methods considered are spectral and wavelet analysis, bandpass filters [5]. A further distinction can be made regarding the position of the sensors installed. Rolling stock-based solutions, where accelerometers are installed onboard, proved to be the most effective solutions [6], as they allow to monitor the status of both the infrastructure and vehicle components. Examples of rolling stock-based solutions designed for monitoring both track irregularity and vehicle dynamics are provided in [7]-[9].

In this context, the target of the article is to propose innovative methodologies for data processing and analysis of experimental signals collected onboard, during long-term monitoring of in-service vehicles. The main focus is that of ensuring the safety of the system, with particular attention devoted to hunting instability occurrence. To this aim, synthetic indexes representative of vehicle dynamics (such as RMS acceleration values) have been considered, together with evolution both in time and with respect to the position along the railway line. It is worth noticing that the proposed condition monitoring approach is suitable for various rail transportation systems, ranging from metro to main line.

2 Methods

In this scenario, the aim is that of developing and testing a methodology for data processing and analysis, starting form bogie acceleration signals recorded during a rail vehicle monitoring campaign. Out of the several possible purposes of condition monitoring activities, major attention is devoted to hunting instability phenomena, in the light of its relevance concerning safety issues.

The geometry of the railway line, track irregularities and wheel/rail coupled profiles have a strong influence on vehicle dynamics. Therefore, monitoring the evolution of running dynamics requires precise identification of the train position. Consequently, map-matching algorithm aimed at properly locating data gathered onboard represents a crucial step for monitoring purpose [10]. In order to associate all the acquired signals to the corresponding line section where they have been measured, a suitable strategy relies on the GPS position stored during train's passenger service. It is worth noticing that nowadays, for safety reasons, rail vehicles are often equipped with GPS receiver indeed. The proposed algorithm has been designed such that GPS positions stored by the train control unit are compared to the rail line GPS coordinates provided by the infrastructure manager. Once data geo-localization has been completed, acceleration measurement gathered onboard (properly associated to the corresponding mileage) can be processed so as to compute synthetic indexes representative of vehicle and infrastructure status.

The developed algorithms for data processing and analysis have been validated against experimental data collected in recent years by the Department of Mechanical Engineering of Politecnico di Milano during continuous monitoring campaign carried out both in metro and main lines. The aim is that of verifying whether data gathered onboard can be used for predictive maintenance purposes of both vehicle and infrastructure.

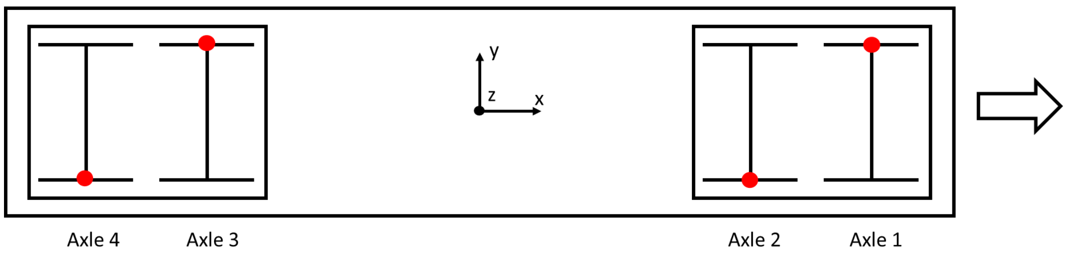

Figure 1: Measurement setup of a vehicle instrumented for rolling stock condition monitoring: the four red dots indicate the mounting positions of the accelerometers installed on the bogie frames.

A typical rolling stock measurement setup is shown in Figure 1: it relies on triaxial accelerometers mounted on the bogie frames, installed in correspondence of each wheelset of the vehicle in a configuration suitable for measuring both vertical and lateral running dynamics.

The synthetic indexes computed allow to investigate vehicle dynamics evolution both in time and with respect to the position along the railway line. In particular, the RMS value of the bogie lateral acceleration in the 6-10 Hz frequency range was computed on a spatial window of 100 m, so as to identify possible instability occurrences along the line.

3 Results

An example of the proposed procedure for data processing and analysis is illustrated hereafter.

As a first step, the samples of the RMS lateral acceleration collected along an entire railway line during two different periods of 1 month each have been considered from a statistical viewpoint, without associating them to the train position along the line. The collected data have been analysed by computing their 5^{th}, 50^{th} and 95^{th} percentiles.

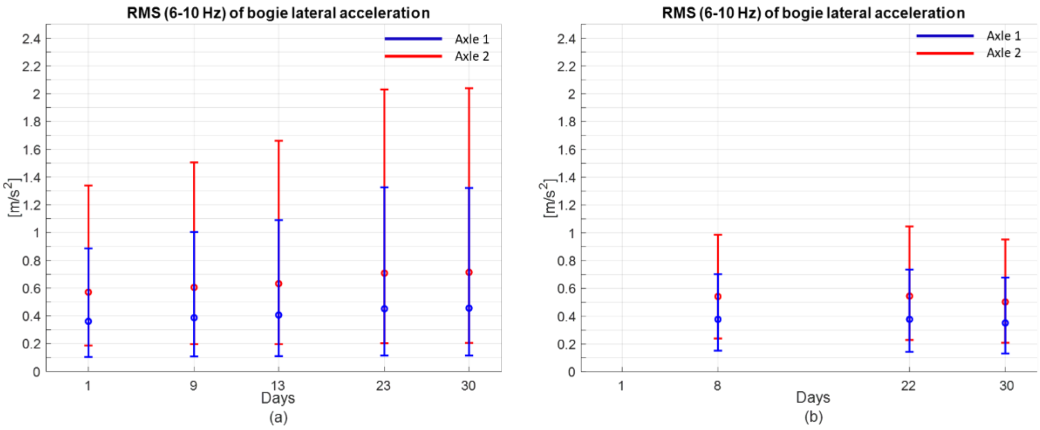

Figure 2: Statistical analysis of bogie RMS lateral acceleration: 1 month evolution of the 5^{th}, 50^{th} and 95^{th} percentiles of the distributions of RMS values before (a) and after (b) wheel re-profiling.

The results of Figure 2(a) clearly point out the progressive increase of the proposed instability index, which is associated to the wheel/rail profiles wear. Comparing the two axles of the same bogie, the rear one (Axle 2) results to be more sensitive to hunting instability. Data reported in Figure 2(b) have been measured after wheel re-profiling (note that no significant evolution is observed after maintenance intervention).

In the second step of the analysis, the data collected onboard are associated to the train position along the railway line and compared to relate vehicle dynamics evolution to the local track conditions, thus enabling the possibility to identify critical track sections that may need maintenance actions. Figure 3 shows an example of the analysis carried out on the samples of the RMS bogie lateral acceleration (computed in the 6-10 Hz frequency range along spatial windows of 100 m, as for the data processing of Figure 2), collected in a 3 months period. The analysis relies on a chromatic representation of the RMS samples: once that a predetermined threshold value T of the RMS lateral acceleration is fixed, corresponding green, yellow and red bands are obtained (respectively 0-0.4T, 0.4T-0.8T and in excess of 0.8T).

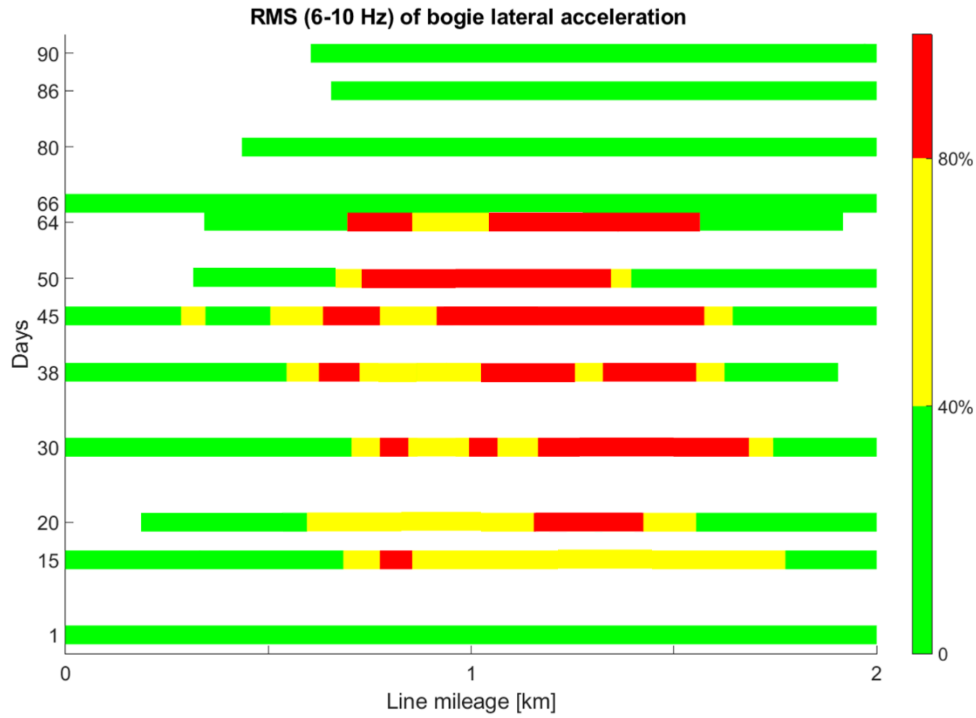

Figure 3: Evolution of the RMS bogie lateral acceleration with time at fixed line mileage position.

The proposed methodology allows identifying those track sections which are mainly involved in hunting instability phenomena, as well as monitoring their evolution with time. During the first 64 days, the deterioration of the axle acceleration levels over the considered track section is evidenced by the green-yellow-red transition. The green indexes observed in the subsequent period (days from 66 to 90) are a clear consequence of the maintenance operations made on the track which prevent unstable dynamic conditions to occur.

4 Conclusions and Contributions

Nowadays, railway infrastructure is pushed towards its limit operative capacity: high-speed trains fleets are not only increasing, but also aiming to achieve higher performances in terms of maximum speed allowed. Monitoring activity of both rolling stock equipment performances and railway lines are then of fundamental importance. As a result, CBM is becoming a preferable choice for the railway industry stakeholder. In the article, a methodology for data processing and analysis of data gathered during condition monitoring campaign has been presented, which is believed to be useful to support CBM. The proposed methodology relies on accelerometer signals measured onboard of an in-service passenger vehicle. It is worth noticing that the algorithms

presented are suitable for various rail transportation systems, ranging from metro to main line.
The accelerations measured have been processed so as to compute synthetic indexes and they have been related to the corresponding position along the line where they have been gathered by means of proper geo-localization algorithm.
Two different data analysis approaches were proposed. The first one concentrates on the index evolution and investigates how the train running dynamics changes with time as a consequence of wheel/rail profile wear and track irregularity degradation. The results highlighted progressive increase of the index due to the wheel/rail profiles wear and identified rear wheelsets to suffer from hunting instability the most. The second one, instead, relates vehicle dynamics to local phenomena along the line and to the evolution of track maintenance conditions. Instability growth was often identified as a localized phenomenon, resulting from wheel/rail profiles coupling evolution as wear proceeds. One of the main outcomes of the proposed methodology is the possibility of continuously monitoring track quality and identifying potential critical sections along the line that may need to be inspected, to decide whether dedicated maintenance actions are necessary.
In conclusion, the benefits of the proposed methodology range from monitoring rail vehicle dynamics evolution keeping safety steadily under control, to the possibility of efficiently plan maintenance interventions.

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