An Innovative Model-Based Dynamic Weigh in Motion System for Railway Vehicles

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Abstract

An accurate dynamic estimation of the axle loads of running railway vehicles and an estimation of the position of the vehicle center of mass are fundamental and represent an important topic in the railway safety and traffic management. Weigh-in-Motion (WIM) systems [1] are aimed at the dynamic weighing of railway vehicles (without stopping the vehicles), making use of different measurement stations localized along the track. The goal of the proposed work is the development of an innovative WIM estimation algorithm, able to estimate the axle and wheel loads and the position of the center of mass of a generic train composition by means of track measurements. The proposed solution is capable of manage different types of experimental and simulated input data (rail shear, rail bending, vertical forces on the sleepers) and to perform the estimation at high vehicle speeds. The WIM algorithm processes the set of experimental physical quantities chosen as track inputs by means of estimation procedures based on least square minimization techniques. The procedure is based on an accurate 3D multibody model of a benchmark vehicle (Manchester Wagon) and on a detailed 3D flexible model of the railway track, including a set of 3D beams, connected to sleepers and ballast models by means of visco-elastic force elements. An exhaustive simulation campaign has been made in order to verify the algorithm accuracy and robustness. Several running conditions have been reproduced to test the robustness of the WIM algorithm performances in different operating conditions (even when experimental data are not available), characterized by several values of the parameters that influence the dynamic response of the system (vehicle speed, car body mass, load distribution, stiffness and damping of the track, etc.). The general architecture of the developed WIM algorithm is illustrated in Fig.1 and it is composed of two principal parts: the physical model and the estimation algorithm.

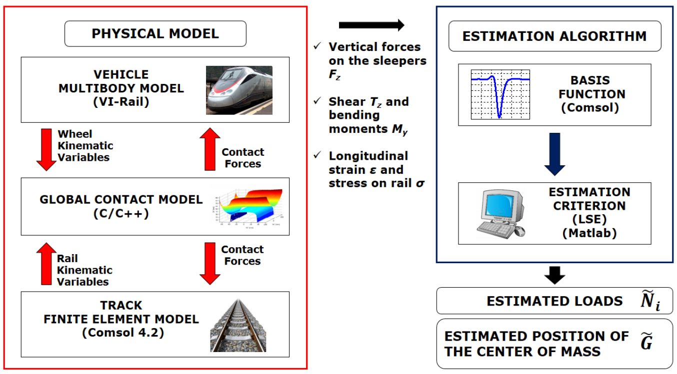

Figure 1: General architecture of the WIM system.

The first one consists of the 3D accurate multibody model of the investigated vehicle (implemented in Adams VI-Rail environment) and the 3D flexible multibody of the track (developed in Comsol environment) that interact online through a 3D global contact model developed and validated by the authors in previous work [2][3] and improved to be used in this application. The estimation part is composed by an innovative algorithm (implemented in Matlab) and the basis functions generator (developed in Comsol

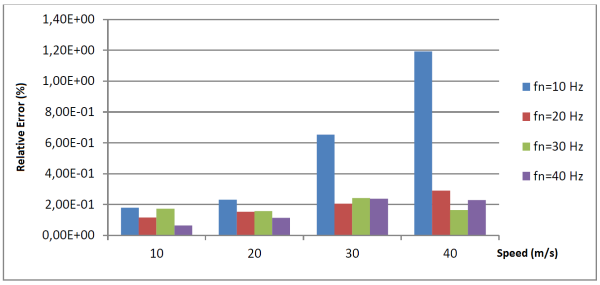

Figure 2: Behaviour of the percentage relative error as a function of speed V and cut-off frequency f_n with M=20 t.

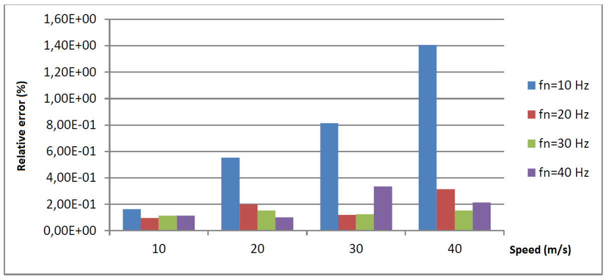

Figure 3: Behaviour of the percentage relative error as a function of speed V and cut-off frequency f_n with M=50 t.

and generated through the model described above). The basis functions represent a set of solutions produced by a single load, related to a single wheel or axle travelling along track. The algorithm is based on a QLH (Quasi linearity hypothesis) and considers the effects of every crossing loads due to the wheels independent from each other. Thanks to the QLH, it is possible to reproduce the signal input produced by the whole train, as a linear combination of the model basis functions: in this way the estimated quantities are obtained from the coefficients of the linear combination. In this work the algorithm makes use of the measurement of the vertical forces acting on the sleepers performed by force sensitive elements placed over the sleepers (but the algorithm can manage different types of input signals as rail shear and bending, longitudinal stresses and strain on rail). These forces (simulated F_z^{sim} if provided by a physical model of the railway track or real F_z^{sp} if coming from experimental data), represent the physical track inputs of the *WIM* algorithm that, starting from the knowledge of these quantities, estimates the wheel or axle load $\widehat{N}$ and the position of the vehicle center of mass. The global performance of the *WIM* algorithm have been studied by considering the maximum relative error $e_{\max}^{sim}(V,M,f_n)$ for each wheel (right and left side of each axle), obtained by varying the vehicle speed V, car body mass M and cut-off frequency f_n of the measurement chain and analysing the maximum error values $e_{\max}^{sim}(V,M,f_n)$:

$$e_{\max}^{sim} = \left\| e^{sim} \right\|_{\infty} = \max_{1 \le i \le n_{tot},} \left| max(e_{Ri}^{sim}, e_{Li}^{sim}) \right| \tag{1}$$

where e_{Ri}^{sim} and e_{Li}^{sim} are the relative errors on the estimated right and left loads of the i-th axle.
The algorithm performance have been studied both in nominal conditions and in perturbed ones (robustness analysis), by varying the stiffness and damping of the track (sleeper and ballast and a combination of them, see Table. 1).

Table 1: Relative percentage error on estimated loads with uncertainty on sleeper and ballast vertical stiffness and vertical damping for different values of speed V.

Architecture 1	Speed V 20 m/s	Speed V 40 m/s
$K_{z,sl} \rightarrow$ + 10 % $C_{z,sl} \rightarrow$ + 10 % $K_{z,bal} \rightarrow$ + 10 % $C_{z,bal} \rightarrow$ + 10 %	1.927 %	2.808 %
$K_{z,sl} \rightarrow$ - 10 % $C_{z,sl} \rightarrow$ - 10 % $K_{z,bal} \rightarrow$ - 10 % $C_{z,bal} \rightarrow$ - 10 %	1.937 %	2.477 %

Results have shown the good accuracy and robustness of the proposed approach for all the considered operative conditions and with different vehicle and track parameters and various measurement chains.

References

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