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An innovative algorithm for the evaluation of wheel - rail contact points based on Neural Networks

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Abstract

The multibody simulation of a railway vehicle requires a reliable efficient method to solve the wheel-rail contact problem. From a more general point of view this problem can be represented as the model of the contact between two bodies having generic three dimensional surfaces and can be divided in three main parts: contact geometry, contact kinematics and contact mechanics. Contact geometry deals with the research of the contact points between the bodies. Contact kinematics allows to calculate, from the displacement and velocities of the contact bodies, the relative speed in the contact points. The contact mechanics finally calculates the forces exchanged in the contact points between the bodies: their direction and magnitude depend on the location of the contact point and on the relative speed between the contact bodies in these points. The paper describes a series of studies concerning the first part of the problem: the research of the contact points. The aim of the work is then the development of a method for the evaluation of the positions of all contact points between wheel and rail, and its implementation in a multibody simulator of the railway vehicle dynamics. Different solutions of this problem are present in the literature and are implemented in the commercial multibody softwares (MSC Adams, Simpack etc.) for real-time calculations.

The procedures for the calculation of the contact points can be divided in two main grups: in the *on-line* implementation, for each single step of simulation, the research method is applied to obtain the coordinates of contact points. In the *off-line* implementation the research method is used to realize a look-up table that contains the position of contact points at given relative positions of wheel and rail; during the simulation the position of contact points for the current relative position is interpolated using the informations in the table. The *off-line* calculation is commonly implemented in the multibody software simulators because the time necessary to read the look up tables is strongly faster than the direct application of the research procedures.

The problem of the individuation of contact points, from a mathematical point of view can be represented as the evaluation of the local minima of a real multi dimensional function. The methods available

in literature can be distinguished in two main groups: the methods based on the value of the function and the methods based on the derivatives of the function. The main problems and limitations of the above mentioned methods based on the evaluation of the function are related to the computational costs and to the simplifications that are introduced (not all the degrees of freedoms are considered, the number of contact points is limited etc.). Numerical iterative algorithms could be applied to the problem of minimization without simplifying the geometry of the problem. However these methods, with or without simplifying hypothesis, require a calculation time which is unsuited for a on line implementation and real-time analysis; therefore these methods require a former calculation of look-up tables. Moreover the main drawbacks of the numerical iterative algorithms in several dimensions are related to the definition of the starting points and the assurance of the convergence and accuracy.

Methods based on derivatives apply the definition of minimizer: for a real valued function $f(\mathbf{x})$, a point is a minimum when all the first order partial derivatives vanish, and the Hessian matrix, which contains the second order partial derivatives, is positive definite. The advantages of this type of approach are: no simplifications are made, multiple contact points can be easily managed, the computational costs decrease significantly. The weak spot of these semi-analytic procedures is that the computation time is not yet as small as real time applications needs.

An application of neural networks to the wheel-rail contact problem is then proposed in order to further reduce the time of evaluation of contact points. This type of models are often referred as black box models. In a model with neural networks, the mathematical model of a problem is decided by the user, disregarding the physical laws which describe the analyzed system. The capacity of the model to reflect the analyzed problem is given by a certain number of parameters, which value is set in a procedure known as training, which needs a certain number of reference data. The training process is iterative, and is stopped when the model, with the current set of parameters, reflects the behavior of the physical problem. The solution with neural networks requires the collection of a set of data, which are necessary for the training. In the proposed implementation the sets of data were obtained by the over mentioned semi-analytic method. The advantages of the proposed method are mainly related to the computational performance: no iterative calculations are needed, the analytical form is very simple (only multiplications and simple functions have to be applied), so few calculations are required. The main advantages of the semi-analytic methods are maintained: there is no upper limit to the number of minima (training with semi-analytical methods); however the neural network based implementation requires lower computational time and then are suitable for an online real time implementation. The weak spot of neural networks is that the process of training requires a long calculation time, and it must be done again if the profile of wheel or rail has to be changed. Anyway this process can be performed once for each wheel/rail profile pair and does not require a relevant direct human contribution, so it can be easily automated.

The substantial difference between the classical approaches (numerical and semi-analytic methods) and neural networks is that the former solve the problem in its exact form, but during simulations they need interpolation between data contained in a table, while the latter use an approximation of the problem, but give a continuous output.

The paper will summarize the formulation of the analytic methods and will describe the details of the implementation based on the neural network. The results obtained with the different solutions will be shown and compared.