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Estimation of Wheelset Equivalent Conicity using the Dual Extended Kalman Filter

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Abstract

Control and monitoring of a railway vehicle require the precise knowledge of the states and parameters of different parts of the vehicle. It can be difficult in practice to obtain those by direct measurements. Therefore, estimation based on a series of other measured quantities can be a possibility. State estimation is generally used in the control of railway vehicles to provide information on unmeasurable signals to a control unit, while parameter estimation has been used as a monitoring technique [1]. Model-based estimators, which are widely used in vehicle control and monitoring, commonly use fixed parameters. In railway vehicles, time-varying parameters, especially the nonlinearities of wheel-rail interface properties, substantially influence the dynamic behaviour of the vehicle. The accurate knowledge of time-varying parameters is therefore important to achieve an effective estimator.

The wheelset conicity plays an important role in the movements of the wheelset. Knowing the instantaneous conicity value would enable active wheelset steering that ensures stability on straight tracks without impairing curving properties. Equivalent conicity is a dimensionless measure of wheelset conicity defined as the change of rolling radius between the left and right wheels as a function of the relative lateral displacement. This parameter is unmeasurable and highly nonlinear depending on the shape of a wheel and rail. This paper demonstrates the implementation of the dual extended Kalman filter (DEKF) [2] [3] aiming at identifying the wheelset equivalent conicity of passenger railway vehicles while negotiating a curve. The synthesized DEKF estimator employs a two-stage discrete-time extended Kalman filter method combining state and parameter filters concurrently running in parallel as shown in Figure 1. The state estimator is derived from a half-vehicle model with seven degrees of freedom; the lateral and yaw motions of two wheelsets, described by lateral velocity $\dot{y}_{wi}$ and yaw velocity $\dot{\psi}_{wi}$ ($i = 1{,}2$); the lateral and yaw motions of a bogie frame, i.e. $\dot{y}_b$ and $\dot{\psi}_b$; and the lateral motion of a half carbody described by lateral velocity ($\dot{y}_{cb}$). Track curvature and track cant are also considered as states for the joint estimation to obtain the information of track inputs. The measurement model, in consideration of practical implementation, includes acceleration sensors measuring at axle boxes ($\ddot{y}_{w1}$ and $\ddot{y}_{w2}$) and a rate gyroscope measuring bogie frame yaw velocity ($\dot{\psi}_b$).

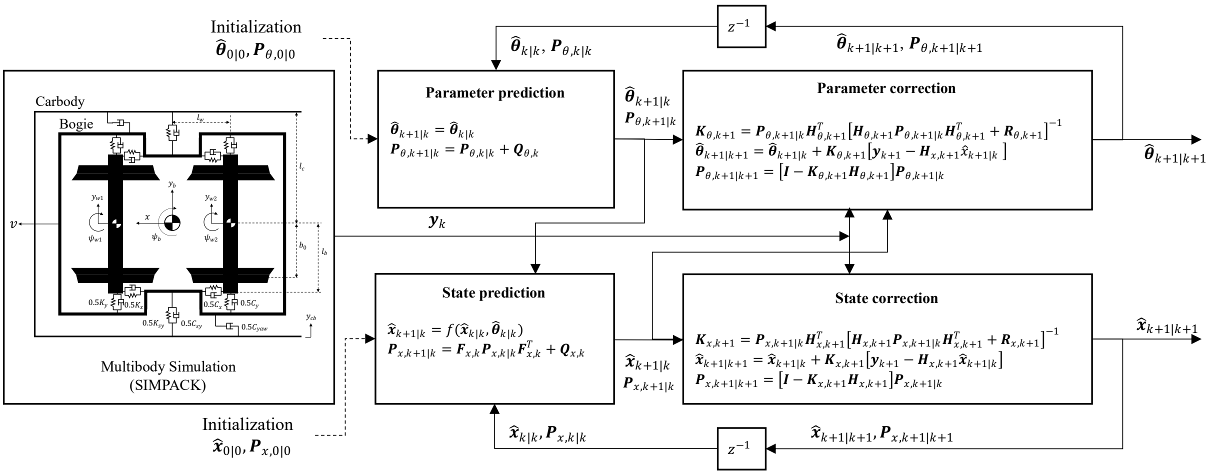
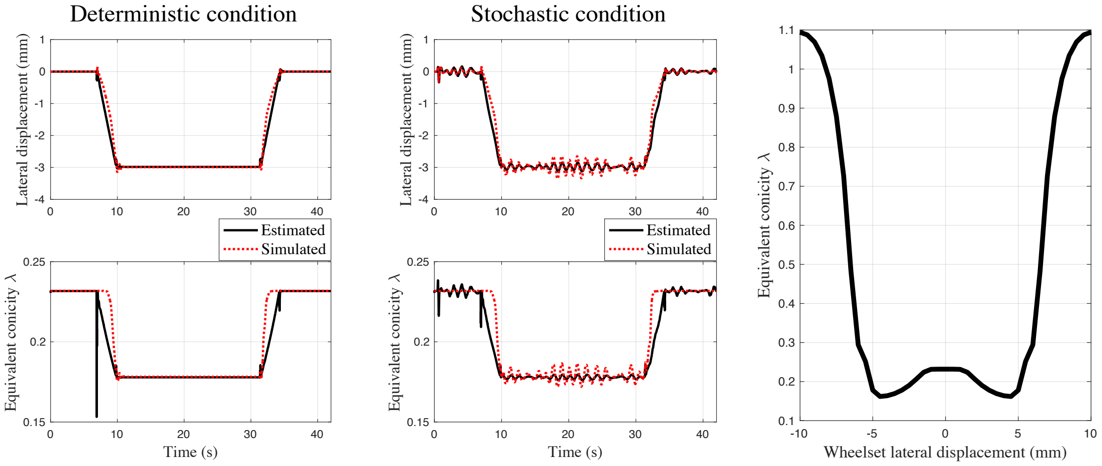


Figure 1: DEKF estimation algorithm

The vehicle used in this paper is a high-speed railway vehicle consisting of two bogies with two suspension levels. Simulations with both deterministic and stochastic excitations using the multibody simulation software SIMPACK are carried out at an operating speed of 250 km/h on a curved track of 2800 m radius and a track cant of 160 mm. Track irregularities in lateral direction using low ERRI PSD [4] are introduced as stochastic track features.



(a) (b) (c)

Figure 2: DEKF of deterministic (a) and stochastic (b) track inputs and equivalent conicity (c)

Figures 2a and 2b show that the estimated lateral displacements of the leading wheelset ($\hat{y}_{w1}$) are superimposed with the ones acquired from SIMPACK. The parameter estimator gives a good estimate of the equivalent conicity ($\hat{\lambda}_{eq}$), especially in tangent track and steady-state curving; however, it is more sensitive than state estimation in terms of process noises and choice of parameters' initial values. The nonlinearity of the equivalent conicity function as shown in Figure 2c for a S1002 wheel and a UIC 60 rail with rail cant 1:40 also affects the effectiveness of the parameter estimation.

Table 1: Root mean square errors (RMSE) of the estimation

Bodies	Deterministic track		Stochastic track	
	y (mm)	λ_{eq}	y (mm)	λ_{eq}
Front wheelset	0.156	7.687e-3	0.168	7.634e-3
Rear wheelset	0.103	0.701e-3	0.111	0.908e-3

Table 1 provides a summary of the estimation errors, which are the root mean square (RMS) values of the difference between estimated and simulated values, for lateral displacement and equivalent conicity. The promising results with acceptable errors stated in Table 1 for both deterministic and stochastic track conditions indicate the reliability and adequate performance of the designed DEKF estimator. Thus, this approach has the capability to quantify the time-varying wheelset equivalent conicity. The results demonstrate the feasibility of utilizing this DEKF method in railway vehicle applications as the knowledge of time-varying parameters is not only important in achieving an effective estimator for vehicle control but also useful for vehicle monitoring.

References

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