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Motorcycle State Estimation for Lateral Dynamics

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Abstract

The motorcycle lean (or roll) angle development is one of the main characteristics of motorcycle lateral dynamics. Control of motorcycle motions require an accurate assessment of this quantity and for safety applications also the risk of sliding needs to be considered. Direct measurement of the roll angle and tyre slip is not available, therefore a method of model-based estimation is developed to estimate the state of a motorcycle. This paper investigates the feasibility of such a Motorcycle State Estimator (MCSE). A simplified analytic dynamic model of a motorcycle is developed by comparison to an extended multi-body model of the motorcycle, designed in Matlab/SimMechanics. The analytic model is used inside an Extended Kalman Filter (EKF). Experimental results on an instrumented Yamaha FJR1300 motorcycle show that the MCSE is a feasible concept for obtaining signals related to the lateral dynamics of the motorcycle.

Model development

In this feasibility study, it is chosen to use a model-based estimation algorithm: the Extended Kalman filter. The basis of such algorithms is formed by an analytic representation of the observed system, in this case a motorcycle. The objective is to achieve a real-time application and the resulting model has been a challenging compromise between accuracy and computational demand. In this respect, the internal estimation model has been set up to describe the lateral dynamics at constant velocity only. To find out which degrees of freedom should be modelled, first an extensive multi-body representation of the actual motorcycle has been set up in SimMechanics. The tyres have been modelled using Delft-Tyre [1], such that realistic tyre behaviour (e.g. tyre cross-section, combined slip) is accounted for. This multi-body model is validated using experimental results obtained from test drives with an instrumented Yamaha FJR1300 motorcycle. Several model configurations, which could potentially be used inside an EKF, have been compared with the multi-body model in order to select the concept for implementation in the EKF. The selected motorcycle model has 7 degrees of freedom being the forward velocity (v_x), lateral velocity (v_y), yaw rate (r), roll angle (ϕ), steering angle (δ), front wheel angular velocity (ω_f) and rear wheel angular velocity (ω_r). Linear tyre slip characteristics are used. For this model, the equations of motion are derived using the Lagrange energy equations. The model is similar to the motorcycle model in [2], however, the motorcycle model in this paper will not be linearised for the roll and steering angle. The result is a non-linear model, which is valid for all roll and steering angles:

$$
\begin{array}{rcl} \dot{x} & = & f(x,u) \\ z & = & h(x) \end{array} \quad \text{with:} \quad \begin{array}{rcl} u & = & \left[\begin{array}{ccc} \delta & \omega_f & \omega_r \end{array}\right]^T \\ x & = & \left[\begin{array}{ccccc} v_x & v_y & r & \dot{\phi} & \phi \end{array}\right]^T \\ z & = & \left[\begin{array}{ccc} a_x^s & a_y^s & \dot{\psi}^s \end{array}\right]^T \end{array} \tag{1}
$$

Here, the sensor equation z contains all sensors which are used by the EKF: longitudinal a_x^s and lateral acceleration a_y^s and yaw rate $\dot{\psi}^s$. Note that due to the model concept the state estimator is valid only for relatively constant forward velocities. Furthermore, as linear tyre behaviour is implemented without, extreme sliding situations are out of the validity region as well.

State Estimator setup and results

Because the internal model is non-linear, the Motorcycle State Estimator (MCSE) is set up using an Extended Kalman Filter method [3]. TNO has adapted this method earlier in its Vehicle State Estimator (VSE) for passenger cars in order to account for non-linear tyre behaviour and as a result, the VSE gives reliable lateral slip estimation over the full operating range [4, 5]. The MCSE algorithm is written in C-code and compiled onto a real-time platform, dSPACE MicroAutobox, which is located in the top case of the experimental motorcycle. The MCSE runs with a sample frequency of $100\,Hz$. As an example, the experimental results for a slalom manoeuvre are presented in Fig.1. From the results in Fig.1, it can be seen that the roll angle is estimated well.

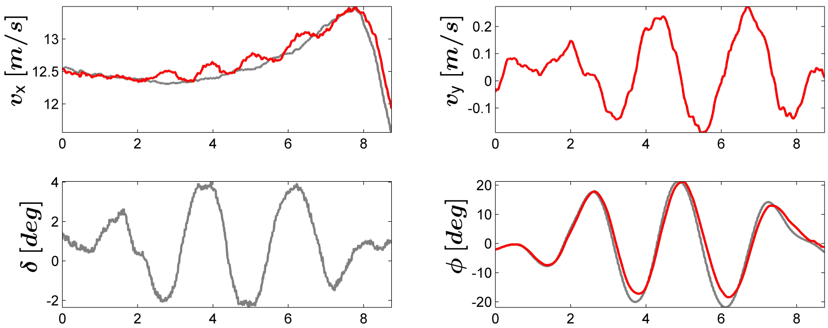

Figure 1. Experimental results of the MCSE: forward velocity v_x, lateral velocity v_y, steering angle δ and roll angle ϕ. Estimated signals are red, reference measurements are grey.

Conclusion

An Extended Kalman Filter has proven to be a feasible way for creating a Motorcycle State Estimator for lateral motions with sufficient accuracy and practical computation demands. The accuracy of the MCSE is related to the internal model description of the motorcycle and its validity range. The MCSE concept has been evaluated for roll angles up to 40 degrees. To improve the performance for a wider application range, future development should focus on extending the internal motorcycle model for longitudinal behaviour and modelling of more realistic tyre behaviour.

References

[1] http://www.delft-tyre.com

[2] H. B. Pacejka, *Tyre and Vehicle Dynamics*, Butterworth and Heinemann, Oxford, 2002.

[3] Dan Simon, *Optimal State Estimation*, John Wiley & Sons, Hoboken, 2006.

[4] J. Zuurbier, P. Bremmer, *State Estimation for Integrated Vehicle Dynamics Control*, Proc., AVEC ’02 (#094), Hiroshima (Japan), 2002.

[5] J. Zuurbier, N.J. Schouten, R. Leenen, *Central State Estimator for Vehicle Control Systems*, Proc., JSAE (paper number 20075048), May 2007.