Bicycle and Motorcycle Dynamics 2010
Symposium on the Dynamics and Control of Single Track Vehicles,
20 - 22 October 2010, Delft, The Netherlands

An eleven degrees of freedom dynamic model of a motorcycle

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Abstract

A motorcycle model with eleven degrees of freedom has been derived. The model is a set of nonlinear differential equations that describe the motion of the motorcycle as a function of the forces acting on the separate bodies. The model derived differs from most models in literature in that the rolling wheel is not modeled as a nonholonomic constraint, but includes a simple linear tire model, that is capable of predicting tire forces at large camber angles. The wheels are not restricted to the ground surface, so that wheelies and stoppies can be simulated with this model. Furthermore, the model is fully nonlinear and lateral and longitudinal dynamics are united.

A symbolic expression for the nonlinear equations of motion has been obtained. The motorcycle model that has been created has 11 degrees of freedom, 6 degrees of freedom for the motorcycle as an object in 3 dimensional space, rotation of the wheels, front and rear suspension, and the freedom to steer. The model originates from Lagrangian Mechanics. The way of modeling is originated from robot modeling [2], where the tire contact patches have similar meaning as the robot end effector. The model includes a dynamic mass matrix, a Christoffel matrix, and a set of nonlinear functions in the generalized coordinates and generalized velocities describing the tire forces, suspension forces, brake torques, engine torque, and steering torque. The Mass matrix contains about 18.000 characters. The Christoffel matrix 80.000, and the applied forces are expressed in 360.000 characters, from which 240.000 characters are in use by the front wheel contact patch force and moment. This figure can go down by 90 % by using subexpressions, and a different set of generalized coordinates.

In the equations of motion, steering torque, engine torque, and brake torque are used as control inputs. Furthermore, the model has been linearized and compared with the model of Koenen [3], and with the Jbike6 [4]. A bifurcation diagram has been made where the eigenvalues are calculated for different forward speeds. The eigenvalues with the parameters of the Jbike6 inserted in the model can be seen in figure (2). Comparison shows a positive correlation with both models. Furthermore, the model is compared against another nonlinear model, made in SimMechanics. This model shows similar dynamics to machine precision accuracy.

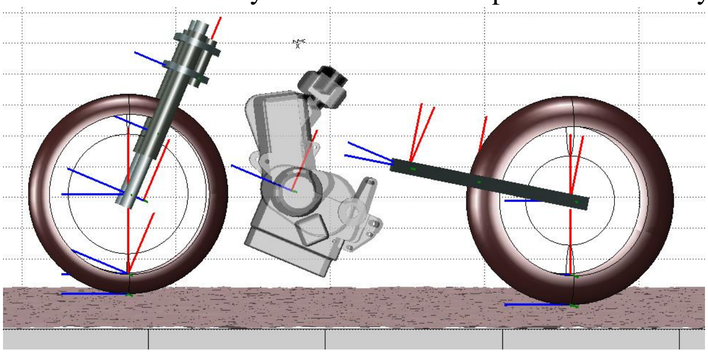

Figure 1. Motorcycle side view.

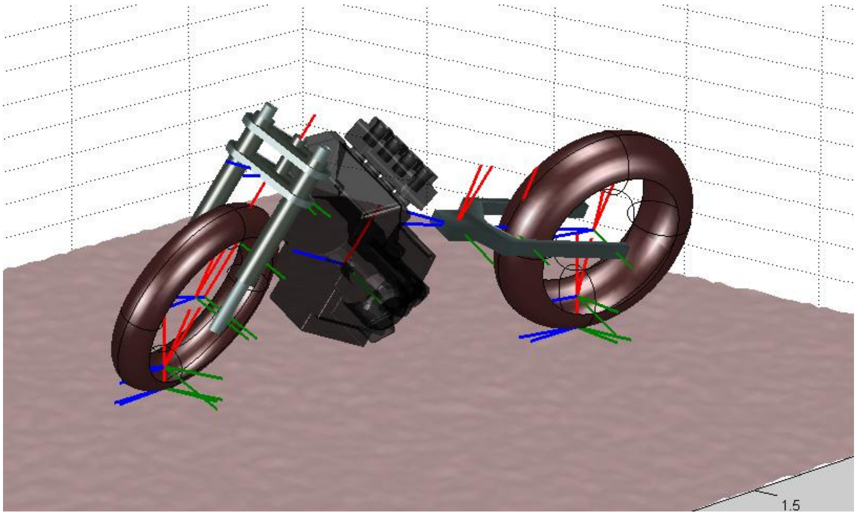

Figure 2. Three dimensional view of the motorcycle model

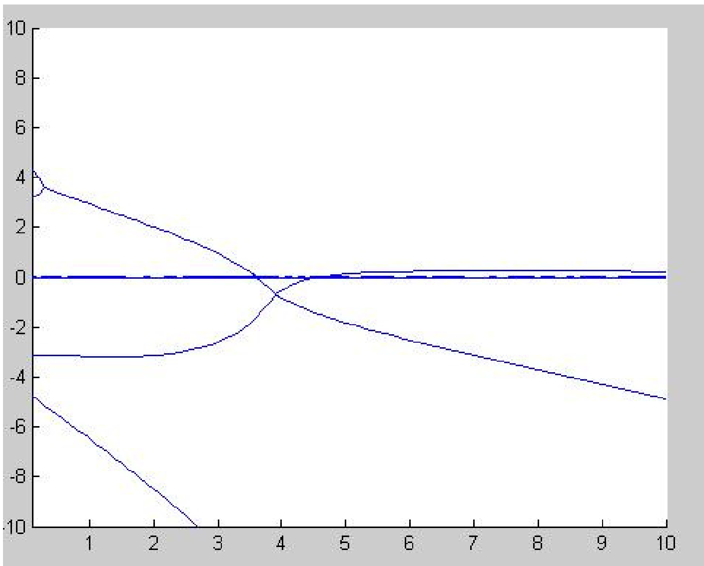

Figure 2. Bifurcation diagram of the linearized model with the Jbike6 parameters inserted

References

[1] M.L. Psiaki, *Bicycle Stability A Mathematical and Numerical Analysis*, B.A. Thesis, Princeton University, June 1979.

[2] M. W. Spong, S. Hutchinson, and M. Vidyasagar, *Robot Modeling and Control*, John Wiley & Sons, Inc., New York, 2006.

[3] Koenen, C., *'The dynamic behaviour of a motorcycle when running straight ahead and when cornering'*, Doctoral Dissertation, Delft University, 1983.

[4] A. L. Schwab, J. P. Meijaard, and J. M. Papadopoulos, *"Benchmark results on the linearized equations of motion of an uncontrolled bicycle."* Proc. Second Asian Conference on Multibody Dynamics., pp. 1–9, August, 2004