High-Fidelity Multibody Model for a Powered-Two-Wheeler Driving Simulator

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Abstract

Nowadays, simulators are widely applied for rider training in many different fields, providing a safe and cost effective learning environment. The simulator aimed is implemented by means of a physical test rig and a virtual environment. The test rig resembles a real Powered-Two-Wheeler (PTW) with typical controls (such as throttle, brakes, indicators, etc.) mounted on a 6 Degrees Of Freedom (DOF) motion base. In the virtual environment, the driving scenario is recreated and shown by means of a head mounted display. The system described above is controlled according to the realistic dynamics of a PTW high-fidelity Multibody Simulation (MBS) model.

The model is a representation of a city scooter composed by 21 rigid bodies and 21 ideal joints, with a total of 15 DOF. Both the front and rear suspension stiffness and damping curves are correlated and validated experimentally. Particular attention has been dedicated to tire modeling, because of their role of transferring forces between the vehicle and the road surface and because of their highly non linear properties. The tire parameters have been accurately measured in order to reproduce the vehicle dynamics in the most accurate way. Because of the implementation in a model-in-the-loop (MIL) set-up, the complexity of the model has to be chosen in order to minimize the CPU time and guarantee real-time performance.

In order to analyze some typical maneuvers that a rider, during the training on the simulator, will have to perform, it has been decided to add a rider model. Maneuvers performed to analyze the PTW model and performance range between dynamic excitations, such as slalom and lane change [1], and steady-state circle maneuver at constant speed [2]. The intrinsically unstable dynamics of the two-wheeler makes it necessary a dedicated algorithm to model the behavior of the rider. Many different strategies are available in literature for rider modeling [3] which resemble the inputs and reactions of a human rider to different levels of fidelity. It has been decided to adopt the concept explained in [4] where the control strategy is divided in three main components: tracking algorithm, longitudinal and lateral controller.

The first important aspect is the tracking algorithm used to compute the scooter position with respect to a predefined trajectory for each time step. The position of the vehicle is described by a set of curvilinear coordinates that are obtained by projecting the velocity vector on the reference path and then integrating the resulting terms [5].

For the longitudinal dynamics a Proportional-Integral-Derivative (PID) controller with “look-ahead” is used to control the vehicle speed. In this case, the term “look-ahead” is used to indicate that the control action is computed based on the difference between the actual scooter speed and the desired speed at a future point (called the look-ahead point) which travels a distance L_A ahead of the vehicle. In order to reproduce the response of a real rider, this preview distance should depend (at least) on the longitudinal

vehicle speed u and the road curvature κ. In the equation 1 the look-ahead distance is defined in such a way that it increases with the speed, but decreases with the curvature.

$$L_A = f(u,k) = \frac{a_0 + a_1 u + a_2 u^2}{1 + b_1 |\kappa| + b_2 \kappa^2} \tag{1}$$

It is important to notice that the speed profile is predefined and fixed for a certain point of the path, therefore the thrust/braking force is uncoupled with respect to the lateral dynamics.
For the lateral dynamics, the implemented strategy is based on the computation of the reference roll angle of the vehicle in steady turning condition. This value is computed by balancing the values of gravitational and centrifugal acceleration. The steering torque used as input is defined by three components, related with reference roll angle (2a), lateral deviation from the reference trajectory (2b) and steering rate (2c). The total steering torque will be the sum of these three components.

$$\tau_1 = P_\Phi(\Phi_{ref} - \Phi(t)) + D_\Phi \frac{\partial \Phi(t)}{\partial t} \tag{2a}$$

$$\tau_2 = P_n n(t) + I_n \int n(t)dt + D_n \frac{\partial n(t)}{\partial t} \tag{2b}$$

$$\tau_3 = D_\delta \frac{\partial \delta(t)}{\partial t} \tag{2c}$$

By virtually riding the PTW model through a set of maneuvers it is possible to derive displacements, velocities and accelerations profile. These data can be used to verify whether they stay within the envelope of motion base and also used as a reference input to develop the cueing algorithm used for the simulator. The results obtained appear to be coherent with the results available in literature [6] and the two-wheeler dynamics is reproduced in a realistic way.
The presentation will include a correlation between the virtual and the real model of the vehicle by comparing the results obtained in this work with experimental data. Also the virtual rider model will be compared with empirical data for model validation.

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