Enhanced Braking of E-Scooters

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Abstract:

Electric scooters, termed e-scooters in the following, appeared in traffic some years ago and became increasingly popular since then. Little weight, small dimensions and a comfortable propulsion system add up to an attractive means of transportation, especially for urban areas. The trend towards e-scooters is likely to increase for both, vehicles in private ownership as well as offered by respective sharing companies. The growing popularity of this new type of vehicles is unfortunately accompanied by an increasing number of accidents and injuries, which are frequently reported in media as well as in scientific literature. One might think of numerous causes for e-scooter accidents, ranging from the vehicle itself (e.g. small wheels, unfamiliar handling dynamics), to the rider (e.g. lack of attention, disregard of traffic rules), to the traffic environment (e.g. darkness, interaction with other traffic participants). In particular, however, rider of e-scooters frequently report of problems related to the braking behaviour of e-scooter in ordinary every-day traffic scenarios: low braking deceleration, sudden skidding of the tyres on wet surfaces, complicated and unfamiliar operation of the (electric and/or friction) braking system for the front and rear wheel, misjudgement of achievable decelerations, road grip, etc. These and similar difficulties especially related to the braking behaviour are reported in several actual studies on the driving safety behaviour of e-scooters, see e.g. (Siebert et al., 2021).

To overcome above problems, an intelligent braking system which assists the rider to properly apply the front and rear brakes of the e-scooter, depending on the actual driving condition, might be helpful. Similar Advanced Driver Assistance Systems (ADAS), such as variable brake force distribution, anti-lock braking systems, wheel lift-off prevention etc., are well-known for passenger cars and motorcycles, as well as bicycles, (Pretagostini et al., 2020; Savino et al., 2020; Corno et al., 2018). However, braking (control) strategies devised for these vehicles are not directly applicable to e-scooters, since there are distinctive differences from a vehicle dynamics point of view. These differences concern the vehicle itself (small wheels with little inertia, unknown tyre behaviour, combined electric and friction brakes), as well as in particular the human rider: note that the mass of the rider body by far exceeds the mass of the e-scooter, and that the position of the human rider standing on the footboard is less restricted compared to the sitting position on bicycles and motorcycles; resulting effects on the lateral and longitudinal dynamics behaviour will be discussed in the present study, along with their consequences for control strategies for a combined actuation of the front and rear braking forces for enhanced braking of e-scooters.

A basic model of a motorcycle (Cossalter et al., 2004) was shown in a precedent study of the authors (Klinger et al., 2021) to be suitable for e-scooters as well to cope effects of load transfers and different standing positions of the rider on the braking performance. Based on this model, ideal distributions of the braking forces $S_{1,2}$ to front and rear tyre for different constant decelerations $-\ddot{x}$ (black dotted lines) and different rider positions (green lines) are shown in Fig. 1 (left). Ideal in this case refers to the utilisation of the same braking force coefficient, i.e. the ratio of longitudinal force over actual normal force, at each tyre. It becomes obvious that the composition of ideal braking forces depends non-linearly on the selected deceleration or friction potential, respectively, as well as on the standing position of the rider. These effects can be attributed to the high centre of gravity of the combined vehicle–rider system in relation to the wheelbase, and make it particularly difficult for the rider to apply the right amount of braking force at each tyre to fully utilize the tyre-road friction potential on one hand, and to avoid skidding on the other hand; this in turn makes the idea of an assistance systems very appealing in order to improve the vehicle safety of e-scooters. The latter especially holds true for shared/rental e-scooter, where the riders are typically less familiar with the behaviour of the vehicle.
Figure 1. Left: Ideal brake force distribution for an e-scooter model for different decelerations and different positions of the rider along the footboard (left). Right: E-scooter equipped with measurement devices used in the present study.

In the present study, a simulation model of e-scooter and rider is used, which takes a limited friction potential between the tyres and the road into account, as well as inertial properties of the human rider body. Based on these quantities, strategies especially for emergency braking manoeuvres will be discussed, aiming to assist the rider to provide a suitable total braking force as well as its distribution on the front and rear tyre. Thereby, two goals need to be strived for: (i) to achieve maximal decelerations/minimal stopping distance, (ii) to simultaneously maintain a stable driving condition. The latter involves to prevent a lift-off of the rear wheel, a locking of front or rear wheel, and – more elaborate – to ensure, that the side forces of front and rear tyre necessary to remain in a stable upright position may be transmitted between the tyres and the road. Both, tyre–road friction potential and inertial properties of the vehicle–rider system are presumed to be known at first, and are then gradually replaced by respective values derived by parameter estimation methods.

Model parameter of the simulation model and input signals for the estimation methods are derived from an actual e-scooter, see Fig. 1 (right), equipped with several measurement devices to capture: the steering angle, actual position and velocity via GPS, accelerations and angular rotation rates via an IMU positioned in the aluminium box at the footboard, as well as the rotational speeds of front and rear wheel via hall-sensors and toothed discs. In addition, a Correvit system is used to measure velocities in longitudinal and lateral direction, and in this way to identify the slip quantities of front and rear tyre therefrom. The parameters of a tyre model in longitudinal direction to account for larger slip values at braking manoeuvres will be identified and presented.

References


