41st Danubia-Adria Symposium Advances in Experimental Mechanics
September 23-26, 2025, Kragujevac, Serbia

Extended abstract DOI: 10.46793/41DAS2025.035M

EXPERIMENTAL ANALYSIS OF ELECTRIC SOOTER DYNAMICS

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1. Introduction

In recent years, electric micromobility vehicles (e.g., electric scooters, unicycles, skateboards, one-wheels, and segways) have gained significant popularity. From both traffic and environmental perspectives, micromobility vehicles have benefits, but controlling these vehicles poses a much more significant challenge for users. As a result, an increased number of road accidents involving personal injuries is realized world-wide. Therefore, exploring the dynamics of the vehicle-human system is essential for making micromobility vehicles safer. In our research, we aim to gather information about the motion of an electric scooter. Due to the small size of the vehicle, the rider's movement significantly influences the motion of the vehicle. Therefore, it is essential to acquire data on how the riders move on the vehicle. In this study, we also examine how accurately a neural network-based algorithm can determine the position of the rider's center of mass based on camera footage.

2. Mechanical modeling

The basic mechanical model of scooters, called the Whipple bicycle model [1,2], is shown in Fig. 1. It consists of four rigid bodies: the front and rear wheels, the handlebar-fork assembly, and the body. Considering all the geometric constraints among the bodies, the scooter has 9 degrees of freedom (DoF). Although the kinematic constraints and the assumption of a flat ground reduce further the DoF of the system, the rolling of the wheels on an ideally flat surface is not ensured in real environments. Hence, all the generalized coordinates

$$\mathbf{q}_\mathrm{m} = \begin{bmatrix} X_\mathrm{R} & Y_\mathrm{R} & Z_\mathrm{R} & \psi & \varphi & \vartheta & \delta & \phi_f & \phi_r \end{bmatrix}$$

are needed in order to reconstruct the motion of the scooter from measurement data.

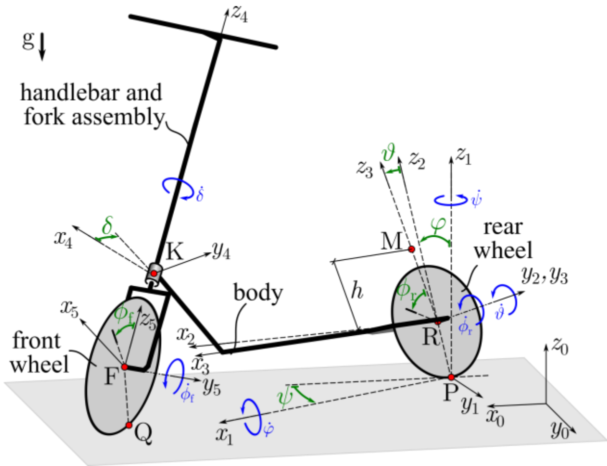

Fig. 1. Mechanical model of the electric scooter [2] with the generalized coordinates indicated.

3. Measuring the states of the scooter

3.1 Position measurement

To determine the global position of the scooter, we use an RTK GPS device, by which an accuracy of up to 5 cm can be achieved if continuous wireless data transmission is ensured for the device from the base station that helps the position correction.

3.2 Velocity measurement

The longitudinal velocity of the scooter is measured via the in-built Hall-effect sensor of the brushless electric motor that drives the Mi Electric Scooter 3. This sensor was used to obtain the rotational speed of the front wheel.

3.3 Steering angle measurement

The steering plays a fundamental role in controlling the scooter. On our experimental scooter, we do not measure the handlebar's angle directly. Instead, we use a timing belt and a pair of pulleys with a 1:1 transmission ratio, and transfer the angular motion to a parallel shaft, making only minimal modifications to the original scooter design. A Novotechnik RFD-4021-736-223-411 sensor is installed on this parallel shaft, which measures with 0.352° resolution.

3.4 Angular position measurement

As shown in Fig. 1., the spatial orientation of the scooter is given by the sequence of rotations: yaw ψ, roll φ, and pitch ϑ. The sensor we used provides the orientation angles of the frame in accordance with this rotation order. The Bosch BNO085 inertial measurement unit (IMU) determines the yaw angle via a magnetometer related to the Earth's magnetic field. The roll and pitch angles are measured based on gyroscope with the accuracy of 0.01°.

4. Detection of the rider's motion state

To obtain the most detailed and accurate understanding of the rider's motion, we equipped the scooter with a camera. This allows us to record video footage in which the rider's movement can be observed. The USB camera records images at a 640×480 resolution with 30 fps. From the resulting video data, we aim to extract relevant information using a neural network-based image analysis. Namely, a skeleton model is fitted by the YOLOv8 algorithm [3], and the center of mass of the rider is estimated based on [4] and the detected positions of the joints. To evaluate the accuracy of this concept, the OptiTrack motion tracking system [5] was also used to determine the real joint positions. The predictions made by YOLOv8 were then compared to these measurements (see Fig. 2.)

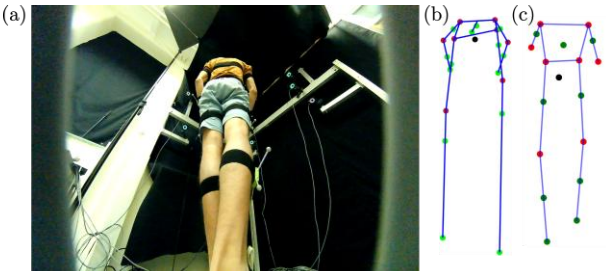

Fig. 2. (a) Snapshot taken with the camera mounted on the scooter, (b) Skeleton model generated via OptiTrack, (c) Skeleton model predicted by YOLOv8 model, along with the estimated center of mass.

Conclusion

The sensor-equipped scooter (see Fig. 3.) provides the opportunity to collect data on the movement of the human-scooter dynamic system and provides a unique opportunity to map human control, even in normal road traffic (see Fig. 4.).

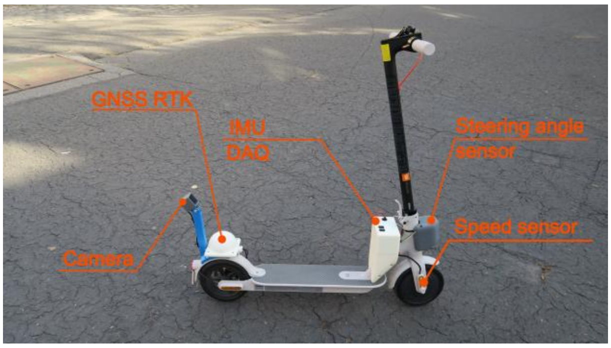

Fig. 3. The electric scooter equipped with a sensors and measurement data collection system

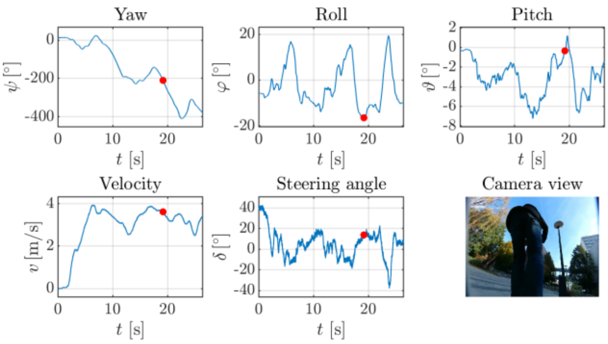

Fig. 4. Measured time signals, the red point indicates the time instant of the camera view.

Acknowledgments

The research was supported by the Bolyai János Research Scholarship of the Hungarian Academy of Sciences, the project NKFI-146201 awarded by the National Research, Development and Innovation Office, the University Research Scholarship Programme (EKÖP), the Ministry of Culture and Innovation, and the National Research, Development and Innovation Fund.

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