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VALIDATION OF A LONGITUDINAL MOTORCYCLE RIDING DYNAMIC MODEL FOR A POWERED TWO-WHEELER INTERACTIVE SIMULATOR

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Abstract. Engine or battery powered two-wheeled vehicles are an essential part of a transport system. Its users are however more vulnerable in comparison with personal vehicles. In general, compared to four-wheel vehicles even a small percentage of accidents that include motorcycles causes a significant rate of all fatalities in the Czech Republic. Two-wheelers nowadays face the challenge of electric propulsion and wider user adoption. This fact emphasizes the need to assess rider's behaviour. One way of examination of rider's behaviour in safe and scientific environments is an interactive vehicle simulator. In order to develop a complex semi-active motorcycle simulator, a virtual model in Unity platform was created. The main purpose of this paper is to verify the longitudinal dynamics of the physical model for emerging interactive simulator. To achieve this goal, crucial parameters of the model were set. For validation of the model we defined several riding scenarios. Based on the data measured during a track test experiment in a real environment, model parameters further needed were indirectly defined. The results show that the output of the longitudinal dynamics model closely correlates with the real data gathered on a track.

Keywords: Riding dynamics, powered two wheelers, vehicle simulator, longitudinal dynamics.

1. Introduction

In the Czech Republic (based on Yearbooks of Road Accidents in the Czech Republic and Traffic 2017-2020, published by the Police of the Czech Republic) we observe a steady ratio of number of road accidents caused by motorcycle riders and total number of people killed in road accidents. It means that 2 % of accidents caused by motorcycle riders stand behind 10 % of people killed. In comparison with cars there is the ratio circa 40-50 % caused road accidents to 60-70 % people killed. This makes us see more than 3 times higher seriousness of accidents caused by motorcycle riders. Compared with the situation in the EU (European Union) the average fatalities percentage is 15 % of total fatalities from 2010 to 2018 based on European Commission (2020) Facts and Figures Motorcyclists and Moped Riders.

Powered Two Wheelers (PTW) are the way to increase mobility and accessibility for citizens. This statement presents the ACEM (the European Association of Motorcycle Manufacturers) in the document Decarbonisation of Transport: Powered Two-Wheelers (PTWs) on the road to 2050. Towards this approach the question of decarbonization and implementation of electric PTW is also mentioned. The similar forecast is also reported in paper [1]. As for the transition to electric PTW we also have to be aware of different risks coming from riders facing electric propulsion of PTW [2]. The rider style can differ significantly. As an extreme example of potential risk of easily available electric micro-mobility vehicles nowadays we present e-scooters. As reported in [3] the injury rate per million miles travelled was 180 times higher than the overall group of motor vehicles.

To assess rider style adaptation to electric propulsion, when using several research methods, it is preferable to perform experiments in driving, respectively riding simulators. As the riding itself could be dangerous and the consequences of small error could lead to several injuries, the simulators are considered a satisfactory way. Similar effects arise when assessing potentially dangerous activities of drivers such as fatigue or aggressive driving styles as documented in [4] and [5]. Concerning motorcycle simulators, the approach turned out to be a successful tool to assess riders' behaviour as presented in [6].

The development of a motorcycle simulator is specific for several reasons. If we compare it with conventional four-wheel simulators, we can determine differences. If we focus on motorcycle riding dynamics from the physical point of view, we can observe several specific effects which we cannot neglect.

A motorcycle is a spontaneously unstable vehicle. If we consider the weight ratio between the rider and the bike, it is clear that the rider's movement affects the COG (Centre of Gravity) of the whole rider-motorcycle system. That is why the manoeuvrability (especially leaning) of powered two wheelers is strongly affected by the rider's changing body position. All of these conditions have to be taken into account when developing a virtual physical model as well as control hardware [7].

In addition to physics, there are other technical challenges such as control and command of the whole motorcycle and its HMI (Human-Machine Interface) system. Another technical specific relate to the visualization of virtual scenery projected to a rider. The rider compared to a driver has a potentially wider range of view including the view near the rider's feet, open rear view or the sky view while looking up. In order to improve the feeling of accurate speed adoption and virtual environment perception the visualization is a significant element of the whole simulation and its devices should be designed precisely [8].

The motorcycle riding simulator reveals challenges typical of PTW such as e.g. roll motion height and vehicle motion controlled by a rider [8]. When we design the simulator the motorcycle physical model is an essential part of the whole structure. This physical model can be divided into two main systems of the straight movement and the turning movement system [7].

Straight forward movement or the so-called longitudinal riding dynamics includes in general acceleration and braking in the motorcycle riding field even shifting gears, recuperation braking and deceleration as a typical feature of each engine or motor type and settings.

Based on findings above we see that PTW causes high percentage of fatalities and that they are an integral part of future mobility planning moreover enlarged by the group of electric PTW. It is important to be able to examine accurately rider's behaviour within the context of electric PTW mobility. It means both the risks and benefits. The safety of testing riders, repeatability and reproducibility is very important. Therefore, we decided to develop a motorcycle simulator aiming at problematic issues of electric propulsion of PTW. One of the main sub-systems of such a simulator is the longitudinal dynamics model. The primary motivation for creation of an accurate longitudinal model is the possibility of future accurate assessment of riders' behaviour in safe environment. One of the key factors of the simulator of electric motorcycle is the authenticity of specific riding propulsion characteristics of longitudinal movement associated with such a motorcycle.

2. Method

Our approach towards accurate longitudinal motorcycle dynamic models combine real test track and virtual computational development in the software Unity. The basis for the following work is the architecture (see Figure 1) of the whole simulator system which is divided into two parts – "Set-up geometry" module, where the basic geometry and mass characteristic of the bike is defined. The second module (see Figure 2) provides the communication between the individual blocks of the physical model as shown in the diagram. This step provides the possibility of a complex view on the whole development and testing.

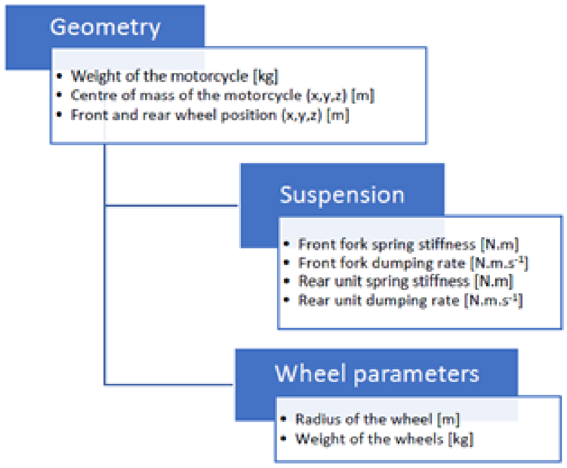

Figure 1. Module 1 – Motorcycle input parameters.

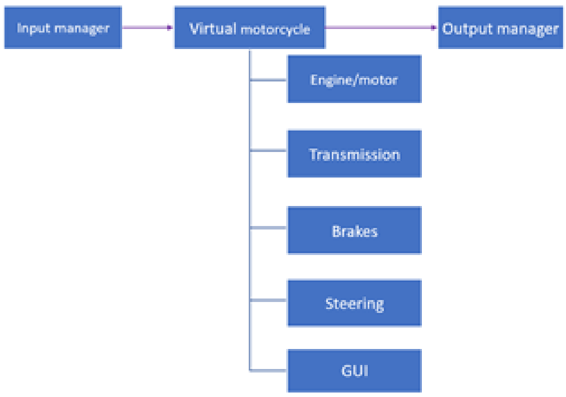

Figure 2. Module 2 – Motorcycle simulator architecture.

As the whole system is developed according to the presented architecture, we created the first draft version of the longitudinal dynamic model able to operate within the system. The following step is to validate the output of the simulations according to the real track test data.

For the testing and as the first steps in the development of the simulator we also consider the future possibility of implementation of control hardware and thus we created a simplified handlebar controller (see Figure 3) able to communicate with the model.

For the validation we defined three motorcycle-rider system movement scenarios. Acceleration from zero up to 80 km·h^{-1}, emergency braking from 80 km·h^{-1}. The third scenario describes the straight free movement from the speed of 80 km·h^{-1} to a complete halt. In this scenario the motorcycle with a rider stops only due to riding resistances of the whole system motorcycle-rider. Test scenarios are defined ideally with 0 % slope and wind speed 0 km·h^{-1}.

In the first longitudinal model parameters set-up we focus on the road motorcycle similar to the category MOTO3 of the world road racing championship.

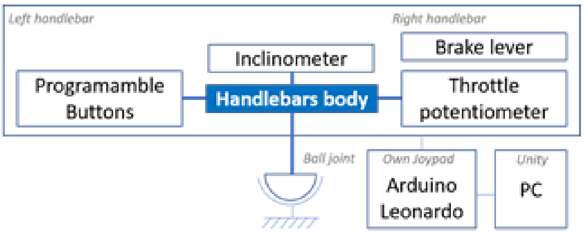

Figure 3. Diagram of the simplified motorcycle handlebar for simulator.

Figure 4. Visualization from the development Unity platform.

Virtual development of environment and visualisation of the bike presents Figure 4. The motorcycle is produced by the student team CTU Lions of the Faculty of Transportation Sciences, Czech Technical University in Prague. Basic parameters are weight of 165 kg, electric motor with peak power up to 42 kW, torque up to 95 Nm. The rider has testing weight of 75 kg. This particular motorcycle (see Figure 5) was used for the measurement for track tests according to the presented scenarios.

For data acquisition we used our self-developed DAQ (Data Acquisition System) verified in a series of previous track tests as presented in [2, 9]. For this application the main parameters were the motorcycle velocity and throttle openings. Data was collected within closed area.

The basis for the validation is the learning algorithm for the exact bike from which the measured data comes from. In the first step we use the scenario of free movement to adjust parameters of riding resistances. Then we use acceleration scenario data. Throttle openings and velocity curves are input to the simulation model. The model afterwards computes the optimal engine power curve to correlate with the input speed curve. Then we tune the parameters of braking to correlate the most with the speed curve in braking scenario.

When the learning phase ends we perform the exact same testing scenario in the unity through the simplified handlebar controller. The data from the virtual testing are stored as the simulation output data and then compared with the input velocity curves. For the evaluation of the accuracy of the longitudinal dynamics model we define a final speed difference error.

Figure 5. Motorcycle used for track test and DAQ.

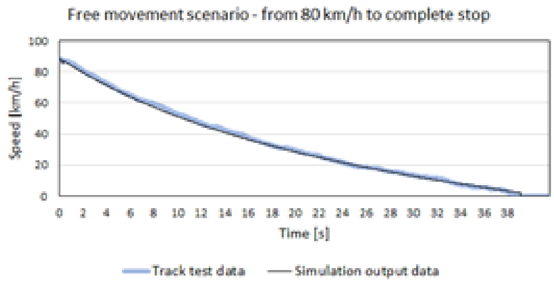

Figure 6. Free movement scenario speed profiles comparison.

3. Results

The results chapter is divided into two parts in compliance with the presented method and testing scenario sequence. In each section the results of the final set-up of the longitudinal dynamics model compared to the data from the track test are presented. The first one focuses on the final speed profiles and the second one looks up closely to the absolute speed differences.

3.1. Speed profiles

Following Figures 6, 7 and 8 present the speed profile within time in the acceleration, braking and free movement testing scenario. We observe very close correlation of the track test and simulation output data. The correlation coefficient in the all three scenarios is almost equal to 1. The track test data are represented by blue line and the simulation output data by black line.

3.2. Speed profiles differences

When we look closely (see Figure 9, 10 and 11) at the speed profiles or to its differences, we see maximal absolute values 2.8 km·h^{-1}. In all cases the speed difference is calculated as test track data minus simulation output data. The total average speed difference values in order of testing scenarios are 0.78 km·h^{-1}, 0.77 km·h^{-1} and 0.24 km·h^{-1}. When the speed simulation output values are higher than test track values the maximal differences are 1.61 km·h^{-1}, 0.57 km·h^{-1} and 2.80 km·h^{-1}. In the opposite situation the max-

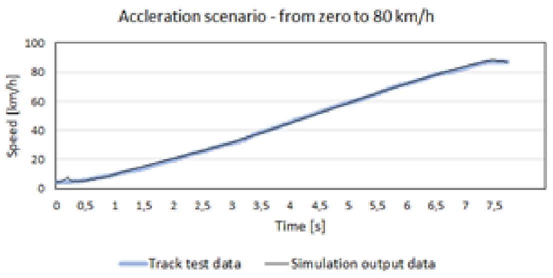

FIGURE 7. Acceleration scenario speed profiles comparison.

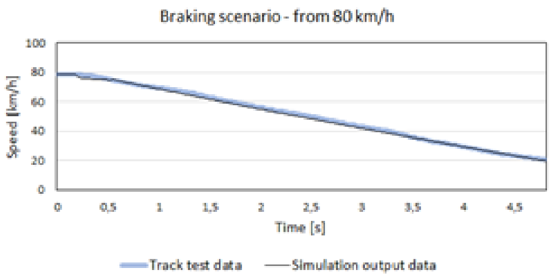

FIGURE 8. Braking scenario speed profiles comparison.

imal differences are 2.63 km·h^{-1}, 2.30 km·h^{-1} and 0.76 km·h^{-1}.

4. Discussion

We performed validation of our motorcycle longitudinal dynamic model. As the result of validation, we see very closely correlating speed profiles of track test and simulation output data. Focusing on the results in the form of speed differences we observe relatively small average values lower than 1 km·h^{-1}. The Maximum speed difference across all scenarios is 2.8 km·h^{-1} after our validation process. This result we find accurate and in proper dimensions based on other studies e.g. [10] where the maximum speed difference in comparable speed level reaches 7.46 km·h^{-1}.

From this point we achieved a very realistic representation of the longitudinal dynamics motorcycle behaviour. The main limitation is the influence of the rider's weight and the rider's aerodynamic position which can cause inaccuracies especially in aerodynamic drag. Both will be subject of further analysis and development. The second main limitation is the fact that this process is oriented on a specific motorcycle. On the other hand, we have very precise simulation outputs. From the simulation point of view the validation process is easily repeatable with new data from track tests.

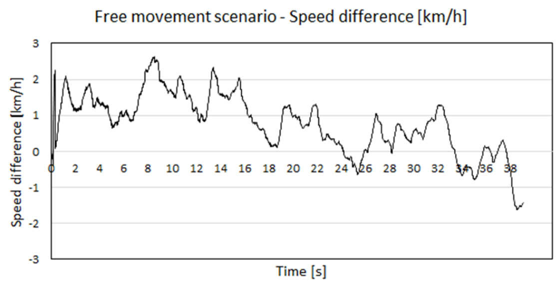

FIGURE 9. Free movement scenario speed profiles deviation.

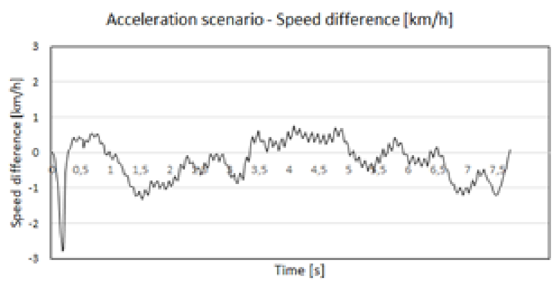

FIGURE 10. Acceleration scenario speed profiles deviation.

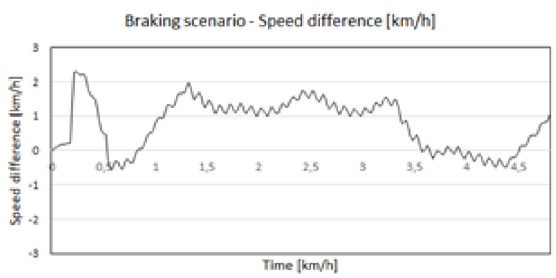

FIGURE 11. Braking scenario speed profiles deviation.

5. Conclusion

Motorcyclists are relatively vulnerable road users. According to the current trends of electromobility, riders are very often facing challenges in form of new propulsion systems of PTW: On the other hand, these new primarily electric PTW are facing unexperienced users. An important fact is that electric propulsion system has many different aspects compared to petrol ones. Thus, riders may behave in a different way. Rider's behaviour assessment in scope of new types of PTW is a path towards safe ride. From this point of view an interactive vehicle simulator serves as a tool for safe testing under laboratory conditions. Focusing more on motorcycle and PTW in general, they have several specifics such as e.g. spontaneous instability.

In this article we validated the longitudinal dynamic model of the interactive motorcycle simulator. Our validation process is designed to reproduce precisely the behaviour of a real motorcycle based on data collected during track tests. We created 3 testing scenarios on which the validation was done. The whole process is applicable to wide palette of motorcycles so that an accurate database of virtual vehicles could be created. We assessed speed profiles of a track test and of an output of simulation. Afterwards we calculated speed profiles deviations. As the results present, the final virtual model precisely reproduces the longitudinal dynamic behaviour within the simulation with maximal speed deviation of $2.8\,\mathrm{km\cdot h^{-1}}$. The limitation of the study is primarily influenced by rider's variable positions that will become the subject of our future research. Our next steps will also aim to validation of other parts of our physical motorcycle simulator model.

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