High Fidelity Dynamic Modeling and Parameter Identification of Autonomous Vehicle Based on Road Tests

Matthew Van Gennip[1] and John McPhee[2]

[1] *Systems Design Engineering, University of Waterloo, mvangenn@uwaterloo.ca*
[2] *Systems Design Engineering, University of Waterloo, mcphee*@uwaterloo.ca

Autonomous vehicles are quickly becoming prevalent these days. There are so many different areas involved in an autonomous vehicle; image processing, path planning, and trajectory generation just to name a few. All of these different areas need to work together in order for the vehicle to actually be able to drive itself safely. One of these vital operations is the ability for the vehicle to actually follow the given trajectory. This is accomplished through use of a controller and a vehicle dynamic model. The controller specifies the proper inputs (steering angle, throttle, and brake) to ensure the vehicle follows the reference trajectory. In order for the controller to know which inputs are needed, a high fidelity vehicle dynamic model is required.

There are many factors to consider when developing a model. If the model is too simple it will not be representative of the actual vehicle, whereas if the model is too complex it will mimic the vehicle accurately but also be much more computationally expensive. This can be an issue in autonomous vehicles, where a high level of accuracy is required, but computational resources are limited. To solve this problem a high fidelity vehicle dynamic model was created using symbolic computing. This maintains the high accuracy necessary for an autonomous vehicle but reduces the computational burden.

Normally parameter identification of a vehicle is done using specialized test equipment in dedicated facilities. For instance the drag coefficient is generally determined by placing the vehicle in a wind tunnel. Likewise the moment of inertia, suspension parameters, and tire parameters are all generally determined through use of specialized equipment in dedicated test facilities. This method of testing is useful due to the level of control available, however it is not always representative of how the vehicle will act on the road. Due to the internal systems of the vehicle, such as antilock braking and electronic stability control, and due to the many unknown interactions between the vehicle and the environment, the vehicle may act differently than expected on the road. Consequentially, if vehicle parameters are identified through on-road testing alone, a better model may be developed.

In order to gather accurate data from road tests a vehicle measurement system (VMS) was used. The VMS consists of three main sensors attached to each of the four wheels. These sensors are the Wheel Force Sensor (WFS), Wheel Position Sensor (WPS), and Laser Ground Sensor/Laser Doppler Velocimeter (LGS/LDV). The WFS consists of a custom wheel hub comprised of strain gauges. These strain gauges measure all three forces and moments on the wheel. There is also a sensor that measures the angular velocity of the wheel. The WPS is a large truss system that consists of five digital encoders that determine the X-Y-Z location of the wheel relative to the chassis along with the camber and toe angles of the wheel. The LGS/LDV consists of five laser sensors. Two of these sensors measure the longitudinal and lateral speed of the vehicle at the tire. The other three sensors measure the current ride height of the vehicle. All of this data was gathered throughout a variety of tests in order to identify the vehicle parameters and create a 14-degree of freedom vehicle dynamic model.

Figure 1 shows the VMS attached to the test vehicle, a 2015 Lincoln MKZ Hybrid. Figure 2 shows the longitudinal tire model developed using only the on-road data. Figure 3 shows how the longitudinal tire model changes under combined slip conditions.

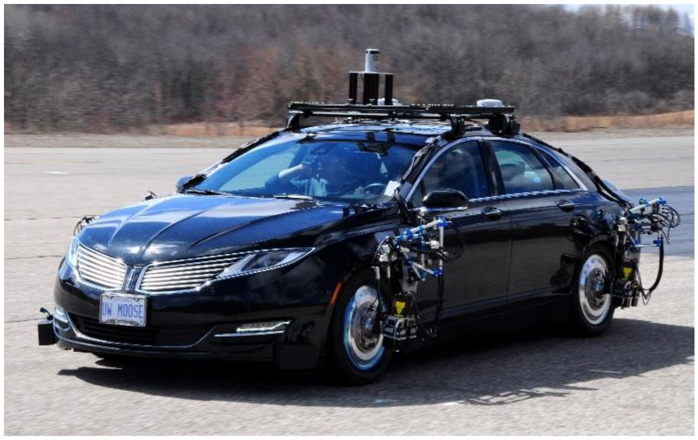

Figure 1: Hybrid Lincoln MKZ with VMS attached

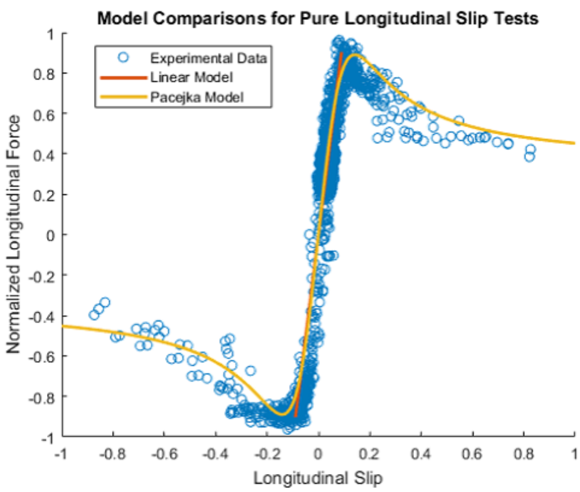

Figure 1: Longitudinal Pacejka Tire Model

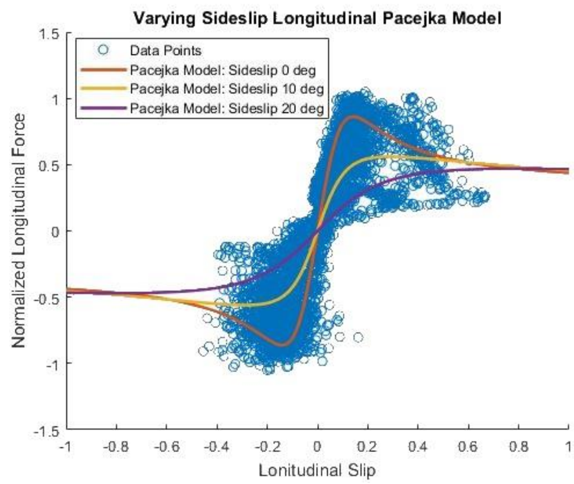

Figure 3: Combined Slip Longitudinal Pacejka Tire Model

Previous papers using the VMS and a similar method have only focused on longitudinal vehicle dynamics. The model developed for the Autonomous 2015 Lincoln MKZ Hybrid vehicle is a full 14 degree of freedom vehicle dynamic model that includes both the longitudinal and lateral dynamics of the vehicle.

References

[1] Buggaveeti, S., Batra, M., McPhee, J., and Azad, N., "Longitudinal Vehicle Dynamics Modeling and Parameter Estimation for Plug-in Hybrid Electric Vehicle," *SAE World Congress*, 2017.

[2] Batra, M., McPhee, J., and Azad, N., "Parameter Identification for a Longitudinal Dynamics Model based on Road Tests of an Electric Vehicle," *ASME IDETC2016-59732*, 2016.

[3] Olofsson, B., Lundahl, K., Berntorp, K., Nielsen, L., "An Investigation of Optimal Vehicle Maneuvers for Different Road Conditions." *IFAC Proceedings Volumes*, Vol 46, Issue 21, pg 66-71, 2013.