VEHICLE DYNAMICS PREDICTION MODULE

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I. INTRODUCTION

Modern automotive industry is focused on self-driving vehicles and needs an appropriate virtual testing environment not only for sensor testing and visualization, but also for vehicle simulation physics and dynamics. Because the simulations of the vehicle physics (and dynamics) are complicated, it is unfeasible to use real-time and online simulations for vehicle trajectory prediction algorithms. This leads to alternative solutions like using the pre-calculated dynamic database.

One of the biggest problems in vehicle dynamics is the tire kinematics behavior. The slip characteristics and the damping of the tires have a big influence on the vehicle steering capacities. The tire slip angle has a non-linear behavior that is a function of the steering angle and acceleration. These features must be considered during the steering path analysis and setting.

II. MODELING

There are three representative vehicles assigned to adjustment and test of the VDPM. At the first step, all the vehicles need to be separated into subsystems: Front and rear axles, steering system, wheels, brakes and powertrain. The body and other subsystems are modeled as a mass point. All these subsystems and road paths are necessary to create the Multi Body System (MBS) model. These subsystems should be validated by natural tests. And then a final full vehicle dynamics validation must be performed.

Once the MBS models are validated, they can be assigned as virtual twins of the vehicles. The next step is to simplify the models without losing precision. This is done by replacing flexible bodies with equivalent simple elements, e.g. anti-roll bars can be modeled as two rigid bodies and equivalent forces.

III.VIRTUAL MANEUVERS

The target of the VDPM use is the prediction and rating of maneuver dynamic parameters of the vehicle. To create a database of maneuvers, it is crucial to parameterize them. Then the parameterized maneuvers are classified as standard maneuvers. If a maneuver cannot be parameterized, it is classified as non-standard. For instance, usually single lane change is designed by smooth paths. The input parameters of the maneuver are: road friction, vehicle speed, longitudinal and lateral target displacement. In the maneuver parameterization step this maneuver will be classified as standard.

IV. PRE-RUN SIMULATIONS

Before the VDPM starts the database generation, the information of the primitive maneuvers functions and the vehicle physical limits must be given. The primitive maneuvers functions are designed using standard functions for the selected self-driving inputs and steering actuator capacities. Therefore, these functions depend on the particular automobile and also on the self-driving algorithms they are generated for. To obtain the vehicle physical limits, it is necessary to study the vehicle capacity to reproduce the required steering inputs inside a safe maneuvering area. To define the physical limits of the vehicle several tests are run. This step gives us the possibility to reach the critical values and dependencies of the automobile dynamic parameters, e.g. the maximum lateral acceleration, as functions of the steering values and steering speeds. The analysis of this information help us to create a rating criteria for the vehicle maneuvers. The steering capacities of a vehicle are represented in figure 1. In this figure, three rating areas can be found. These areas are separated by step steering and smooth maneuvering by the steering path timing. The values of these areas change from vehicle to vehicle. It is also important to note that the higher the steering speed signal is; the lower the steering amplitude the vehicle is able to reproduce. The information about maneuvers and their real values are not presented in this paper because this information is confidential.

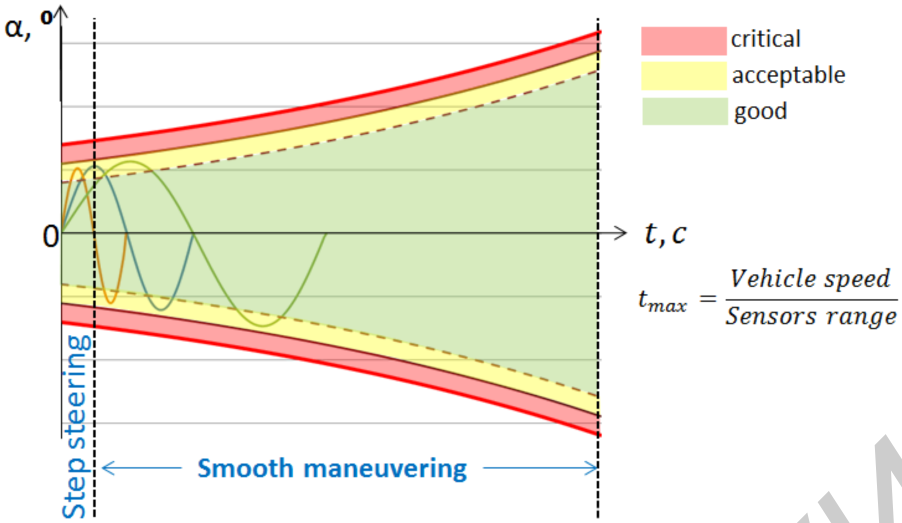

Figure 1 – Steering path working area

V. FITTING ALGORITHM

The procedure of the VDPM is described by the following basic steps:

The autopilot has a task to move from point A to point B. For example, single lane change, shown on the figure 2.

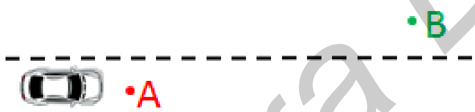

Figure 2 – Single lane change

In this step, the autopilot creates a reference road course from point A to point B. A steering input is calculated by the autopilot algorithms. The steering input is based on the initial conditions of the vehicle at the point A (e.g. velocity, steering angle, etc.). See figure 3.

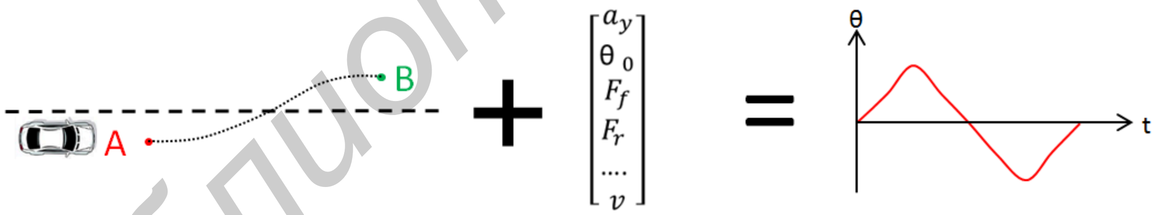

Figure 3 – Maneuver inputs

Then, using the initial conditions of the vehicle and the steering input, the VDPM is able to find a solution from the pre-calculated simple maneuvers database. After a solution with the initial conditions is found, the VDPM compares the autopilot and the database steering input.

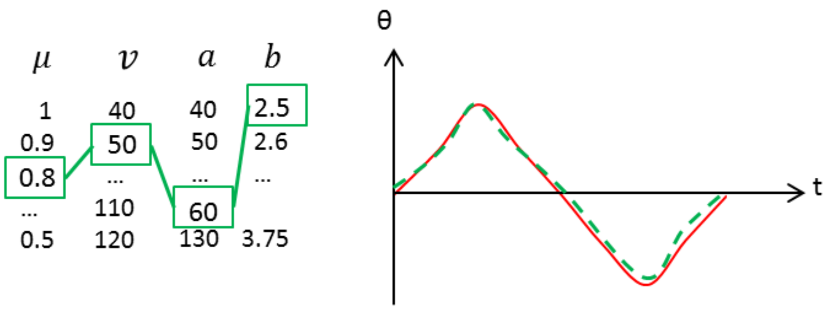

Figure 4 – Maneuver searching

Then the difference (error) between the autopilot and VDPM steering inputs is calculated:

If the error is lower than a defined threshold, the VDMP database outputs the predicted output parameters array. The output parameters describe the vehicle dynamic status on the way from point A to point B. The evaluated output parameters, for example, are:

– Path derivation;
– Wheel Forces balance;
– Lateral acceleration;
– Roll angle;
– Vehicle slip angle
– etc.

If the error is higher than a defined threshold and the steering inputs differs, the VDPM searches a solution with a parameters array based on primitive maneuvers. These maneuvers have a limited number of variations. And all these variations cover every possible dynamic behavior of the vehicle. An interpolation algorithm is responsible of finding the required function and compute the corresponding parameters array.

Once a solution is found, the VDPM creates an output parameters array of the vehicle from point A to point B as an interpolation, and stitches the primitive maneuvers. The created output parameters array describes the vehicle dynamic behavior on the course from point A to point B by discrete steps i. The procedure of the last algorithm can be described as a maneuver division into n steps, based on the vehicle steering response characteristics. The output parameters at step i solution are used as input parameters for searching and interpolate a solution in the database for the next step i+1. At the final step, after all the solutions are found, they are stitched in.

VI. DATABASE OPTIMIZATION AND SPEED UP SEARCHING

There exist vehicle parameters that will not change abruptly while the vehicle is moving, e.g. the velocity or friction coefficient. Therefore, to speed-up the VDPM response, a several number of decisions are fixed:

1. The database has a subordination order, from the parameters with the lower changes during the vehicle movement to the parameters with the higher changes, e.g. the friction coefficient with the road is the first search parameter, then the speed, etc.
2. The VDPM is always working while the vehicle moves, and a corresponding searching corridor is loaded to the memory all the time. The limits of this corridor are the minimum and maximum probable “parameters” moving corridor of the automobile in the current movement case. This corridor permits to constrain the searching process and load only the needed segment of the database.

VI. SUMMARY AND CONCLUSIONS

The three MBS models of the vehicles were created to test and calibrate the VPDM. All these models were optimized to reach more rapid testing without any loss of accuracy on the dynamic behavior of the vehicles.

The VDPM considers the physical limits of the vehicle. Because these limits are known, the VDPM describes all the maneuvers inside safe maneuvering areas. The non-pre-simulated maneuvers (non-standard) are described by stitching primitive maneuvers.

ACKNOWLEDGEMENT

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