Platforms and Algorithms for Autonomous Driving Planning and Control Module

Assignment 1: Vehicle Modeling and Simulation

AA 2024/2025

Deadline: 06/12/2024, 23:59

Introduction

The purpose of this assignment is to familiarize with standard mathematical models used to describe vehicle dynamics. By completing this task, you will gain experience implementing these models and using them for simulation purposes. In this assignment, you will model the dynamics of a vehicle and implement a simulation that will serve for later exercises.

Instructions

- The assignment must be solved individually.
- A short report must be written for each assignment, describing the results, including motivations, observations from the simulations, and any conclusions.
- The report should be concise and clear, with all figures properly labeled, including axes and legends.
- The code should be well-commented to ensure clarity.

- Plagiarism will not be tolerated and will result in points being deducted.
- Submit your work sharing a private GitHub repository or as a zip file.
- Use the template shared. It is sufficient to complete the code with the requests below but you are free to extend it to improve the management of the plots, the writing/structure of the models, save the results in an external file and use the data for plots or something else in a different environment, etc.

Vehicle Parameters

The following vehicle parameters must be used in your simulation models:

- Vehicle mass: $1200\,\mathrm{kg}$
- Inertia: $1792\,\mathrm{kg}\cdot\mathrm{m}^2$
- Vehicle geometry:
  - Front axle to COG distance (l_f): $1.156\,\mathrm{m}$
  - Rear axle to COG distance (l_r): $1.42\,\mathrm{m}$
- Pacejka Magic Formula parameters for tire modeling:
  - $B = 7.1433$, $C = 1.3507$, $D = 1.0489$, $E = -0.0074722$
- Aerodynamic and Rolling Resistance parameters:
  - Air density (ρ): $1.225\,\mathrm{kg/m^3}$
  - Drag coefficient (C_d): 0.3
  - Frontal area (A): $2.2\,\mathrm{m}^2$
  - Rolling resistance coefficient (C_{rr}): 0.015

These parameters have been primarily taken from the CommonRoad repository.

Simulation Outputs

For each exercise, you are required to plot the following outputs:

- Trajectory: x, y
- Heading angle: θ
- Longitudinal velocity: v_x
- Lateral velocity: v_y
- Yaw rate: r
- Front slip angle: α_f
- Rear slip angle: α_r
- Lateral tire force: F_y as a function of slip angle
- Steering angle δ
- Side slip angle β

and reply to the questions, motivating with what is visible in the resulting figures when possible.

Exercises

Exercise 1: Vehicle Modeling and Simulation (Points: 7)

In this exercise, you will complete the template code to include three vehicle models:

- Kinematic model
- Linear model
- Nonlinear model

The simulation should include the following conditions:

- Apply a sinusoidal steering command with a maximum amplitude of 0.1 rad and a frequency of 0.5 Hz.

- Simulate at two constant velocities: 10 m/s and 27 m/s.
- Apply a constant longitudinal acceleration of $1.0\,\mathrm{m/s^2}$.
- Simulate for a duration of 5 seconds with a time step of 0.001 seconds.

Plot the requested outputs for both velocity conditions.

Question: What is the cause of the difference in the slip angle between the linear and nonlinear models?

Exercise 2: Constant Steering and Acceleration (Points: 5)

In this exercise, you will simulate the following:

- Apply a constant steering angle (0.01 rad) and a constant longitudinal acceleration ($1.0\,\mathrm{m/s^2}$) and at a constant velocity of 24 m/s.
- Repeat the same with a constant steering angle (0.055 rad)
- Use a time step of 0.001 seconds and simulate for 5 seconds.

Analyze the results and compare the trajectories and data obtained from the different models.

Question: Do you notice any significant differences between the trajectories or other data obtained from the different models? What is the main cause of the large difference observed in the second test, when the steer angle is increased to 0.1 rad?

Exercise 3: Comparing Numerical Integration Methods (Points: 3)

In this exercise, you will compare the Euler and Runge-Kutta (RK4) methods for numerical integration. Perform the following:

- Simulate the same maneuver as in Exercise 2, but with a time step of 0.04 seconds instead of 0.001 seconds.
- Use the same vehicle parameters and simulation conditions as in Exercise 2, but increase the time step.

Question: Why do you observe a visible difference in the simulation results when comparing Euler's method and RK4 with a time step of 0.04 seconds?

Deliverables

For the submission, you should provide the following:

- A clear and concise report in PDF format, answering the questions posed in the exercises and explaining the observations made from the plots and simulations.
- A well-documented code repository (via GitHub) or a zip file with all the source code.
- Any additional files necessary for the simulation (e.g., external files for saving results).