Theoretical Questions

1. What other sensor would you use in order to create a more robust tracking in cases where there are disturbances? Implement a model of this sensor in the simulation.

In the pure pursuit assignment, only a simple GPS/INS sensor was modulated in order to measure the distance and the orientation of the car from the path.
The disadvantage of the GPS/INS sensor is that it does not warn against disturbances in the road that might prevent a free and safe driving without obstacles.
Therefore in order to alert against obstacles in the road at least two more sensors are advised:

1. Lidar sensor - The lidar is a method for determining ranges by targeting an object with a laser and measuring the time for the reflected light to return to receiver. using the Lidar will assist in alerting from obstacles and disturbances.

2. Vision sensors - vision sensors have the ability of alerting and notifying of disturbances in the road - passengers, obstacles, etc. There are day vision sensors (CCD) and night vision sensors(IR).

In cases of disruptions in the GPS inertial system it is advised to use also:

3. DTM - digital terrain maps that may assist in evaluating the position of the car in absence or corruption of a GPS system. In those cases, the DTM maps may work together with the standalone car gyros.

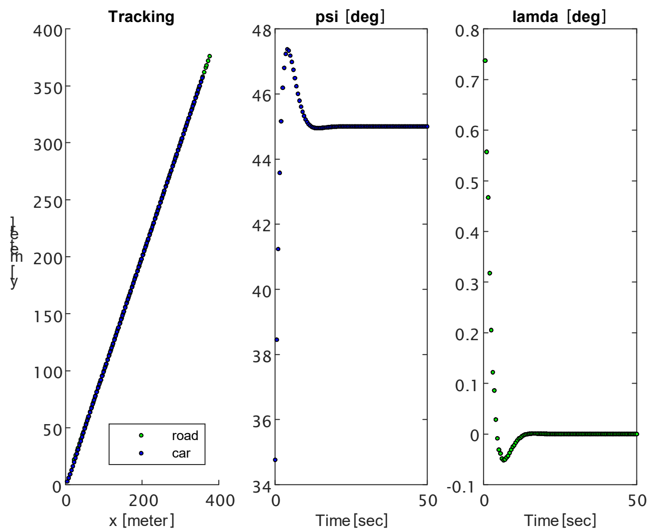
The most proper way of building a robust tracking car system is to combine all of the sensors using a fusion algorithm.

2. What will be the steady state effect of a bias in mechanical road wheel servo? Show this effect in your simulation.

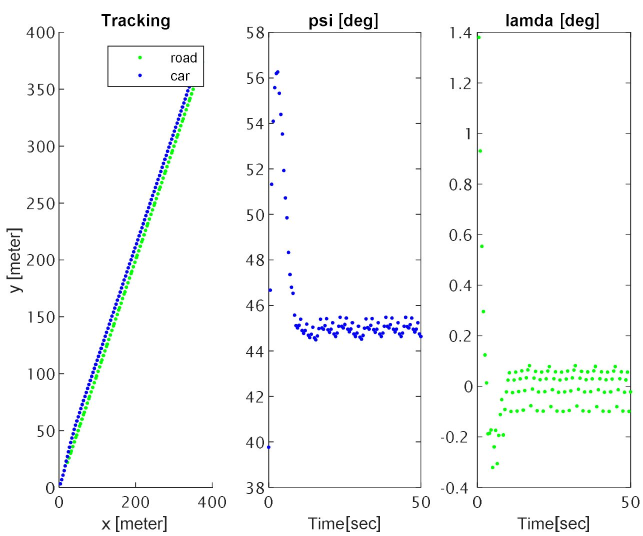
A steady state effect of a bias in the mechanical road wheel servo will prevent the control error to converge and therefore will lead to wheel command δ to jitter around the true car wheel command.

The following graphs - (were generated in matlab environment) show the effect of a 1[deg] bias in the wheel angle versus no bias in the wheel angle.

The scenario depicted in the graphs is of a straight line path that is oriented 45[deg] both to the x&y axis global coordinate system, with an initial car psi angle=30[deg].



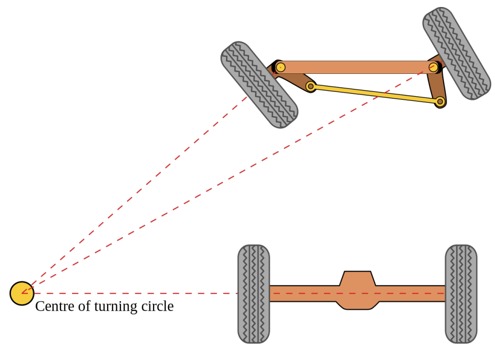
No bias in wheel servo: The wheel angle and the car psi angle converge.



1[deg] bias in wheel servo: The wheel angle and the car psi do not converge and jitter around the true wheel angle.

3. It is known that kinematic bicycle model is only valid in low speed ~ 5 m/sec, suggest a model for higher speeds and state what cannot be neglected anymore?

A model that can be used instead of the kinematic bicycle model is the Ackerman steering model - attached is an image of the model.



The slip wheel angle caused by slippery path cannot be neglected in higher speeds.

4. Explain your consideration for the integration method and step size.

Considerations for integration method:

The state space for updating the car dynamics in the assignment is the following eq-[1]

[eq-1] $$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} v\cos(\delta) \\ v\sin(\delta) \\ v \cdot \tan(\delta)/L \end{bmatrix}$$

where:

x,y - position coordinates.

φ - the car psi angle

v, δ, L - car velocity, wheel angle and length respectively.

A discrete integration method that was used in the simulation is a simplified method suitable for discrete states. however, since the nature of the states above is **continuous,** for that purpose a trapezoid integration method would be more accurate. Below is an example of one state calculated in discrete and trapezoid methods:

$$\begin{aligned} &Discrete: \\ &x(k) = x(k-1) + dt \cdot \dot{x}(k) \end{aligned}$$

$$\begin{aligned} &Trapezoid: \\ &x(k) = x(k-1) + \frac{dt}{2} \cdot (\dot{x}(k) + \dot{x}(k-1)) \end{aligned}$$

Consideration for step size:

The step size reasoning is strictly correlated to the required wheel dynamics. Since the simulation uses a 2[Hz]* bandwidth transfer function from wheel angle command to wheel angle physical angle, a step size of 0.1[sec] was implemented as the computation frequency of the controller of 10[Hz].
The minimum frequency of the controller may be 4[Hz] but in order to have abilities of measuring physical phenomenon such as vibrations, self frequencies and etc. a higher implementation of computation frequency is recommended.
Also, the servo in this simulation is lacking, in the sense that in "real life" we will usually use a velocity loop and a current loop that usually run in much higher frequencies.

*2[Hz] Is a naive consideration for the bandwidth of the wheel angle, As a low bandwidth will not respond to any transient change or spike in the path/road.

5. Choose one component in the simulation and explain how you would improve it in order to get a more real world behavior.

The **car Servo** can be improved in order to get a more real world behavior and accurate modeling using the following sub models:

1. Wheel friction model.
2. Stick slip model.
3. Wheel electrical motor plant dynamics.
4. Control loops and bandwidth (current/voltage, velocity, angle).
5. Disturbances to control loops.
6. Measurements sensors - encoders, gyros, resolvers, etc.
7. Measurements sensor errors and tolerances (bias, scale factors, noise, etc.).
9. System delays
10.BIT (Built in tests) - initial and continuous servo tests.

6. What is needed to be considered on the look ahead distance for the reference look ahead point when the vehicle dynamics are not ideal? (optional)

When the vehicle dynamics are not ideal and contain errors it is important that the look ahead distance would be a trade-of between a long enough distance, that avoids transient phenomenon in the path, but not too long in order to keep with the path.