汽车自动导航控制系统的设计与仿真任务书

This project asks you to design some of the basic components of an autonomous car: the cruise control system and a controller for automatically changing lanes. For the parameters of the vehicle model (masses, lengths, etc), look up or estimate numbers for your car if you own one, or the car of a family member.

You can design and test your controllers using simple linearized models, but then also simulate in SimuLink/Matlab on the true nonlinear coupled dynamics to verify performance.

1. Cruise Control

We assume an engine controller has been designed, so that the control input is the force demanded from the engine.

$$m\dot{v}+\frac{1}{2}A\rho C_D v^2=u+d \tag{1}$$

Here ρ is the density of air in kg/m^3, C_D is a dimensionless drag coefficient, and A is the cross-sectional area of the vehicle in m^2 (looking from the front). Reasonable values for C_D for a car are about 0.25 to 0.45. For your car, look up, measure or estimate A and C_D.

(1) Design a controller that will precisely achieve the desired speed even if there are constant disturbances.

(2) Examine the dynamics of changing from one target speed to another, e.g. 60, 80, 110 km/h.

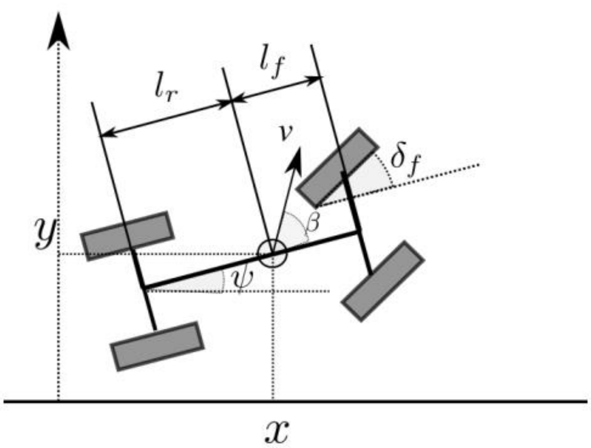
(3) Analyze your controller's response to a disturbance force corresponding to a sudden transition from at ground to a very steep uphill slope of 35% grade.

(4) Examine the effect of uncertainty in mass (e.g. due to the number of passengers).

2. Lateral Control (Lane Changing)

For this section we look at lateral (side-to-side) motion of the vehicle, in particular for automatic lane changes.

A schematic of the vehicle with relevant quantities is shown below. For this question, you should assume $v > 0$ is constant, and the control input is $\dot{\delta}_f$, the steering wheel angle.



The motion of the center of mass position (x, y) is described by the following equations (you might like to verify this, but it is not part of the assignment). Note the coupling to longitudinal dynamics through $v(t)$.

$$\dot{x} = v\cos\left(\psi + \beta\right) \tag{2-1}$$

$$\dot{y} = v\sin\left(\psi + \beta\right) \tag{2-2}$$

$$\dot{\psi} = \frac{v}{l_r}\sin\left(\beta\right) \tag{2-3}$$

$$\tan\left(\beta\right) = \frac{l_r}{l_f + l_r}\tan\left(\delta_f\right) \tag{2-4}$$

$$\dot{\delta}_f = u \tag{2-5}$$

For your car, look up the wheelbase $l_r + l_f$. For simplicity you may assume that $l_r = l_f$.

We assume the vehicle is mostly moving in the x direction, and it is the lateral position y that we want to control.

If we linearize the dynamics about constant speed motion $v(t) \approx v_0$ with small angles, i.e. $\psi \approx 0$, $\beta \approx 0$, $\delta_f \approx 0$, $u \approx 0$ show that we get a transfer function from $\boldsymbol{u}$ to lateral position $\boldsymbol{y}$ that has the form

$$G\left(s\right) = \frac{Cs + D}{s^3}$$

and calculate the values of C and D for your car (note that C and D will depend on v_0).

In addition, your nonlinear simulation should incorporate the following limitations:

(B1) The angle of the steering wheels δ_f should be limited to a reasonable range appropriate for your car.

(B2) The magnitude of $\dot{\delta}_f$, i.e. u, should also be limited to 30 °per second.

Consider the following design questions:

(1) Design a controller that will smoothly and accurately transition from lane to lane.

(2) Simulate the closed-loop system response for lane-change manoeuvres at a variety of speeds, e.g. those you considered for the cruise control.

(3) Improve your control system for a "slalom" motion, where the reference y depends on x: $y_{ref}(x) = 10\sin\left(2\pi x / 50\right)$, i.e. curves 10m each side, with 50m length ways to do a full cycle. Design new controllers to track this reference and answer the following questions: Can you design a single controller that depends smoothly on v? What is the fastest your car can follow this path, with less than 0.3m error in $y - y_{ref}(x)$, and without hitting the limits of steering angle ?

3. Adaptive Cruise Control

Now, as well as your autonomous car (Car A) we consider addition of a radar that senses a vehicle in front (Car B), and the problem is two-fold:

(1) When Car B is more than a *safe distance* away, the system should operate as a regular cruise control.

(2) When Car B is less than or equal to a *safe distance*, the control system should seek to match the velocity of Car B, and maintain a safe distance between Car A and Car B.

You can model the motion of the car in front similarly to your car, except that the car's accelerations are *unknown* to the control system.

The following radar mounted for Car A are being considered: Relative position (on the longitudinal axis) of Car A and Car B. A reasonable model of this sensor as the true range plus a zero-mean Gaussian distributed random variable with standard deviation 0.25m.

Design and evaluate a control system that uses the above relative-position information to achieve the objectives above.

You should verify your control system works well for transitions in and out of the safe zone, and model various realistic but challenging conditions, e.g. sudden braking of the car in front.

In addition, your nonlinear simulation should incorporate "saturation" elements that limit the engine and braking force to realistic values. You should provide references for the values you use. Do you experience any problems using integral control for large changes in reference velocity? How do you overcome them?

4. 仿真报告格式要求

（1） 仿真报告采用 PDF，使用语言：中文/英文均可。正文为小四号宋体或 Times New Roman 11，标题可适当加大字号或用粗体。

（2） 所有报告均在首页标明姓名、学号、班级，文件以“学号-姓名.pdf”的格式保存。

（3） 仿真报告须 15 页以上，并至少包括以下部分：引言、恒速巡航控制、侧向移动控制、自适应巡航控制、结论；对于任一控制仿真部分，须给出对象构建与参数设置、控制器设计与参数设置、仿真曲线与说明等。

（4） 报告中所有图表均需指明标题，其中表格的标题在表的上方，图的标题在图的下方。所有表格与图的标题均为五号宋体。图中***所有曲线采用黑体***，并指明坐标的意义、单位以及大小。对于有多条曲线的，对每条曲线均要表明其含义，并且需通过选用不同的线型或线宽加以区分。

其它事项：

（1）自行成组，每组 2 人，并于本周三前在课程群中上报助教。

（2）仿真报告提交的截止时间：12 月 29 日 24：00

（3）仿真报告（PDF 文件）直接发邮件至：lkdai@zju.edu.cn。