TSFS02 — Vehicle Dynamics and Control

Computer Exercise 3: Electronic Stability Control (ESP)

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Contents

1 Introduction

The main purpose of a stability control system is to aid the driver in critical situations, such as, quick avoidance maneuvers. These systems are often denoted differently for different manufacturers, however, some of the more common abbreviations are ESP (Electronic Stability Program), ESC (Electronic Stability Control), DSC (Dynamic Stability Control), AYC (Active Yaw Control), and VDC (Vehicle Dynamics Control). Throughout this document the abbreviation ESP is used.

The stability control system should compensate under- and oversteer by applying a yaw moment, i.e., a turning moment about the vertical axis. This moment is usually created by braking the individual wheels, but could possibly also be achieved through active steering or applying a driving moment. In the vehicle, these systems are integrated in a control hierarchy together with the ABS, traction control, and other driver aid and safety systems. However, in this exercise you should consider only the ESP.

The main objective in this exercise is to develop and implement your own stability control system, and verify its functionality, using the simulation and modeling tool Dymola.

1.1 Examination

This exercise is carried out in groups of one or two students, and is examined by handing in a report (one report per group). This report should be written as an independent document, so that the reader can understand the content without having read this exercise description first. You should clearly describe the problem you have solved and how you have solved it. This means that you need to describe how you have solved each task (including the preparation tasks), answer all questions, and motivate all assumptions you have made. You should also convince the reader that your implementation works as intended, by including plots/figures and discussions around them.

The report should be handed in no later than 2018-12-19, mailed to victor.fors@liu.se in PDF format.

2 Preparation Tasks

The tasks in this section, i.e., Task 1–6, are preparation tasks that should have been solved before starting with the computer exercise tasks in Section 3. Please verify with an assistant that you have solved these tasks correctly before starting with Task 7–8 (since your code implementations will be based on the equations you derive in the preparation tasks).

2.1 Controller Design

The goal for the ESP is to minimize the difference between a by the driver desired behavior and the actual vehicle behavior. This behavior can be formulated in terms of yaw rate Ω_z and body slip β. If the desired and the actual behavior differs too much, the controller intervenes by applying a yaw moment to help the vehicle turn, or straighten up. This yaw moment ΔM can thus be formulated as a function of Ω_z and β, written as

$$\Delta M = \Delta M(\beta_{nom} - \beta, \Omega_{z,nom} - \Omega_z) \tag{1}$$

where $\Omega_{z,nom}$ and β_{nom} are the nominal values, representing the desired or expected behavior of the vehicle. A simple proportional control can be formulated as

$$\Delta M = k_1(\beta_{nom} - \beta) + k_2(\Omega_{z,nom} - \Omega_z) \tag{2}$$

where k_1 and k_2 are tuning parameters.

Task 1

Determine appropriate expressions for $\Omega_{z,nom}$ and β_{nom}. All included parameters and variables should be explained (for example with figures). Motivate the assumptions you have made and why your expressions are appropriate for describing the desired vehicle behavior.

Task 2

Design a yaw-moment controller, creating a ΔM that is supposed to affect the vehicle. A suggested layout is given by (2). The available sensor signals and necessary parameters are listed in Appendix A.

Task 3

Given your controller design, what signs (positive or negative) should your design parameters have? If you have chosen the design in (2), it is the sign of k_1 and k_2 that are of interest. (A course assistant can help you with a first guess of the absolute values of k_1 and k_2.)

2.2 Controller Actuation

The calculated yaw moment ΔM can be actuated in different ways. Here we will be using a common method, where the wheels are individually braked to create the desired yaw moment.

Task 4

Describe and motivate how the controller decides which wheel to brake in different driving situations. How is the decision affected by the current under-/oversteering state of the vehicle, or which direction the vehicle is turning?

Hint: When applying a braking force (a longitudinal force) at the wheel, the lateral forces will also be affected (think about the friction ellipse). Use this correlation when deciding which wheel to brake.

Task 5

The yaw moment ΔM is now known (from Task 1–3) and you have chosen which wheel to brake (in Task 4). Then the controller needs to know the amplitude of the braking force F_b, that is necessary to generate the yaw moment ΔM. Derive expressions for the brake force F_b as functions of the yaw moment ΔM.

Hint: You may have to use different expressions depending on which wheel you brake.

Task 6

In the Dymola model, the ESP is controlling the braking force F_b with a braking signal $0 \leq u_b \leq 1$ (for each wheel), which is the output from the ESP block. This signal is sent to a brake-force modulator, in which we have a brake-pressure pump that can raise the brake pressure individually for each wheel. For example, the brake line pressure for wheel 1 can be formulated as $p_{b,1} = p_{b,max} u_{b,1}$, where $p_{b,max}$ is the maximum brake line pressure the brake-pressure pump and brake-force modulator can produce. The pressure will act over the two brake-caliper pistons with areas of A_{cp}, pressing the brake pads against the brake disc. The friction coefficient for the brake pads against the brake disc is μ_{bp}. Thus, the total braking force from the brake caliper $F_{caliper}$ can be expressed as

$$F_{caliper} = u_b p_{b,max} 2 A_{cp} \mu_{bp}$$

which is acting on the brake disc at a radius of R_{disc} from the wheel center.

Formulate an expression for the braking signal u_b as a function of the brake force F_b (from Task 5).

3 Computer Exercise Tasks

In the following tasks you should implement and evaluate an ESP based on the controller schemes that you established in the preparation tasks.

Start by downloading the Dymola model `TSFS02_Lab3_ESP.mo` from the course homepage.

Task 7 – ESP implementation

Start Dymola and open the file `TSFS02_Lab3_ESP.mo`, navigate to *TSFS02_Lab3_ESP - Vehicle - Brakes - BrakeComponents - FunctionBlocks - ESP* in the Package Browser window. Implement your ESP controller in the *ESP* block. Note that Dymola uses the FLU (Frontward, Leftward, Upward) coordinate system, meaning the x axis is positive forward, the y axis to the left, and the z axis up.

Remember to include this code as an appendix in your report.

Task 8 – ESP evaluation

In the sub-package *TSFS02_Lab3_ESP - Experiments* you will find two prepared experiments. Use these to demonstrate that your controller operates as intended and that it actually aids the driver when needed. Activate your controller by setting the parameter *ESPOn* to *true*.

The two prepared tests are a Fish-Hook maneuver and an avoidance maneuver:

- Fish-Hook maneuver: A predefined steering signal is fed to the hand wheel, turning the vehicle first slightly to the left, quickly followed by a long right turn. (The resulting vehicle trajectory is similar to a fish hook when seen from above.)
- Avoidance maneuver: A driver model tries to avoid an obstacle in the road. The maneuver is similar to the double lane-change maneuver.

In the graphical view of the experiments, you can also find a parameter called *TrunkLoad*. This is a mass parameter for additional load placed in the trunk of the vehicle, making it more rear heavy than usual. Set this value to 100 kg and see how the vehicle handles with and without your ESP controller activated.

You should in the report clearly show that your controller is working properly. Do this with data plots and possibly also still images from the visualizations, combined with discussions around what is seen in these figures and what you find interesting.

For plotting, you can use the prepared plot functions found in the experiment packages. However, it could be of interest to plot other variables, such as variables inside the ESP controller (compare your nominal values to those achieved). This can be useful for the report, but also to aid troubleshooting during the controller implementation. See Appendix C for a short description on how to plot arbitrary variables in Dymola.

A Vehicle Parameters and Sensors

Table 1 specifies some useful vehicle parameters, and in Table 2 the different measurement signals, available for the ESP controller implementation, are listed.

Table 1 Vehicle parameters.

Parameter	Description	Value	Unit
m	Total vehicle mass	1660	kg
h	CoG height	0.5	m
L	Wheelbase	2.7	m
l_1	CoG to front axle	1.2	m
t_w	Wheel track width	1.5	m
R_w	Wheel radius	0.32	m
$C_{\alpha,f}$	Front cornering stiffness (per wheel)	$67 \cdot 10^3$	N/rad
$C_{\alpha,r}$	Rear cornering stiffness (per wheel)	$62 \cdot 10^3$	N/rad
k_{sw}	Steer ratio (from hand wheel to front wheels)	$\frac{1}{45}$	
A_{cp}	Piston area for the brake calipers	$9.6 \cdot 10^{-4}$	m^2
$p_{b,max}$	Max hydraulic brake line pressure	$2.3 \cdot 10^7$	Pa
R_{disc}	Effective radius of brake discs	0.15	m
μ_{bp}	Friction coefficient of brake pads	0.3	

Table 2 Vehicle sensors for the ESP controller.

Variable	Description	Unit
a_x	Longitudinal acceleration	m/s^2
a_y	Lateral acceleration	m/s^2
v_x	Longitudinal velocity	m/s
Ω_z	Yaw rate	rad/s
ω_1	Wheel velocity; front left	rad/s
ω_2	Wheel velocity; front right	rad/s
ω_3	Wheel velocity; rear left	rad/s
ω_4	Wheel velocity; rear right	rad/s
δ_{sw}	Hand wheel steering angle	rad
F_{bp}	Brake pedal force	N

B Export Plots from Dymola

You can export plots, or still images of animations, as PNG images. Select the plot window you want to export (so that it is "highlighted"). Then go to the menu bar and select *File - Export - Image...*

C Plot Variables in Dymola

Open up a new plot window; *Plot - New Window - New Plot Window* or from the shortcut button. In the Variable Browser window (on the left), find the variables of interest and click on them.

To plot variables from inside your ESP controller, navigate to *vehicle - brakes - modulatorController - eSP*. All the parameters and variables in your ESP block should show up here.

For more general variables, navigate to *vehicle - signalBus*. Here you will find a collection of the most useful (in general) variables for vehicle dynamics studies.