SD2231 – Lecture on Slip Control Lab 1 – Longitudinal Dynamics

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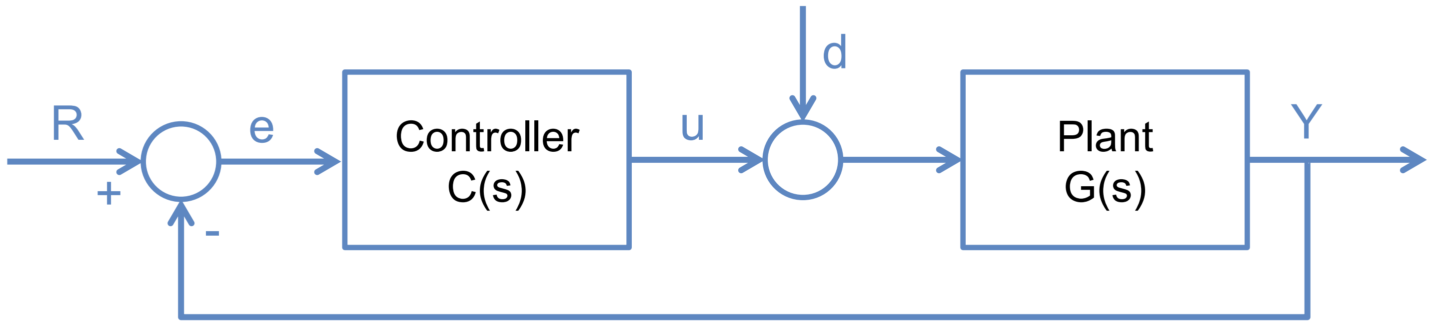
PID control – Closed-loop control system



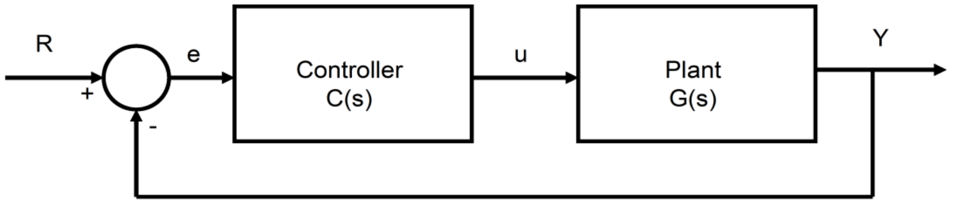
u = actuated variable
d = disturbance
Y = controlled variable
R = reference variable
e = control error

Various options to set up a controller:

→ **We use a PID controller in Lab 1**

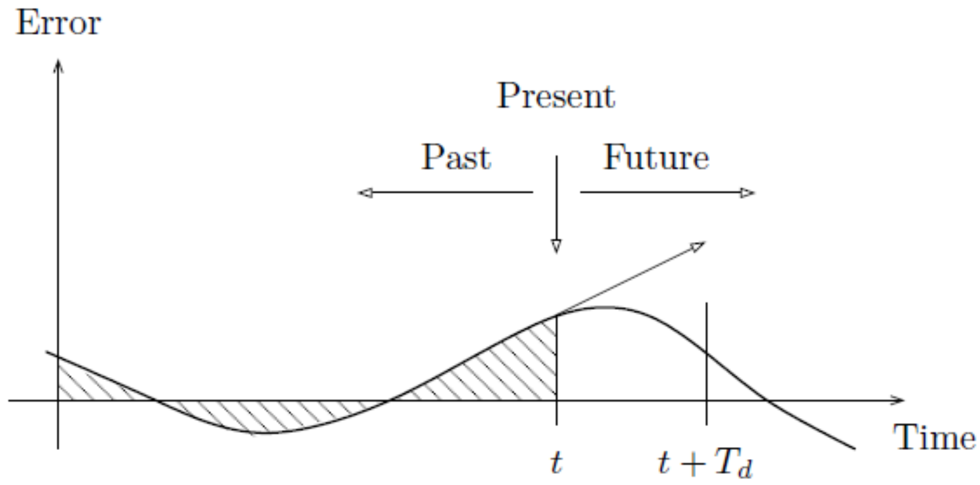
PID control – Basics

- Most common way of feedback control in technical systems.
- Simple three term controller (alternatively one or two terms only).
- Consists of a proportional, an integral and a derivative term.
- General transfer function: $C(s) = K_P + \frac{K_I}{s} + sK_D$
- General function of time: $$u(t) = k_p \cdot \left(e(t) + \frac{1}{T_i} \cdot \int_0^t e(\tau) \cdot d\tau + T_d \frac{de(t)}{dt} \right)$$



PID control – Error minimisation

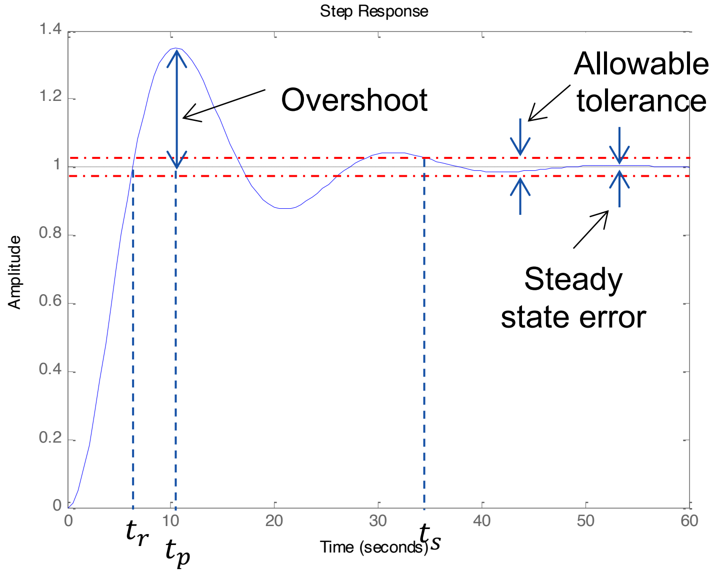
- PID controller takes control actions based on past, present and prediction of future
  → minimize the error



- Proportional, Integral part acts on the present and past values of the error respectively, where the derivative term can be interpreted as a prediction of future errors based on linear extrapolation.

PID control – Characterisation

1. Rise Time (t_r)
   Time it takes for the plant output to rise beyond 90% of the desired level for the first time
2. Overshoot
   Maximum peak value of the response curve measured from the desired response of the system.
3. Settling Time (t_s)
   Time it takes for the system to converge to its steady state within a certain percentage.
4. Steady-state error
   Difference between the actual output and the desired output.

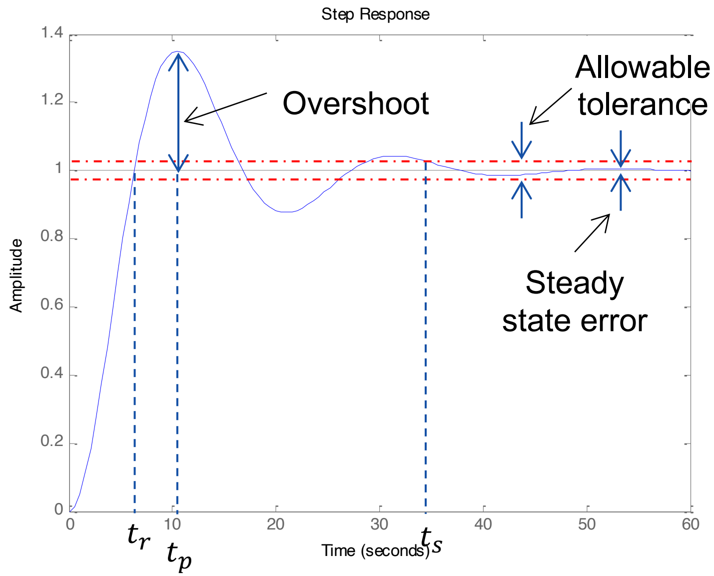


PID control – behavior

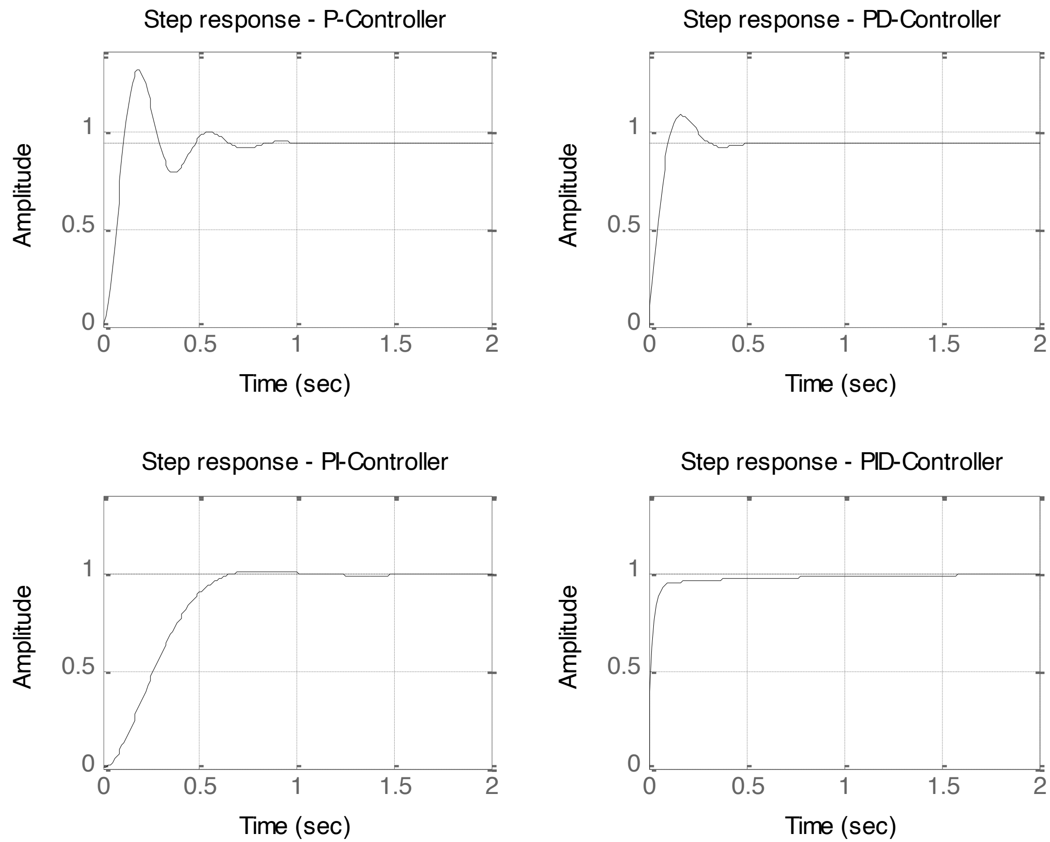
$$C(s) = K_P + sK_I + \frac{K_D}{s}$$

Response	Rise Time	Overshoot	Settling Time	S-S Error
K_P	Decrease	Increase	Small Change	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	Small Change	Decrease	Decrease	No Change

Use as an reference, Kp, Ki, Kd can influence each other to not give the response change indicated above.



PID control – Step responses for different controllers



PID control – Controller design steps

Keep the controller as simple as possible!

1. Obtain an open-loop response and determine what needs to be improved.

2. Determine what characteristics of the system need to be improved.

3. Use K_P to improve the rise time.

4. Use K_D to reduce the overshoot and settling time.

5. Use K_I to eliminate the steady-state error.

6. Adjust each of K_P, K_I and K_D until you obtain a desired overall response. Refer to the table shown earlier to find out the effect of each controller on system characteristics.

Slip control - Definition of slip

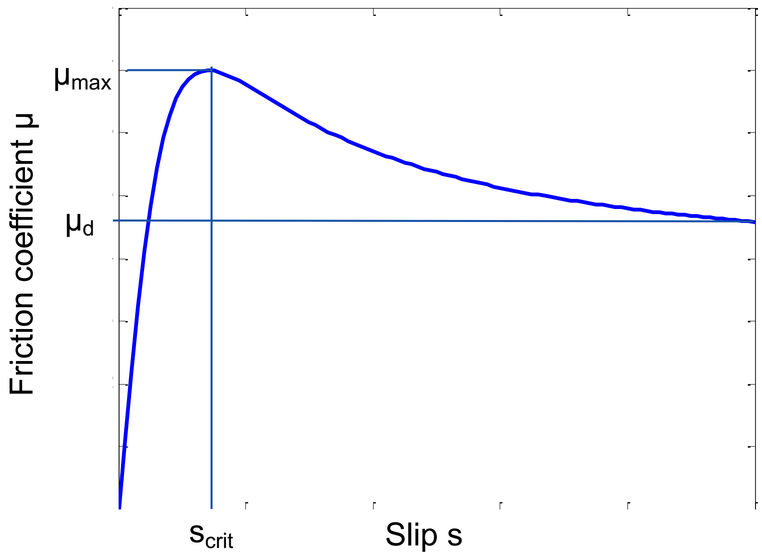
Slip is the difference in speed between the wheel speed and longitudinal speed of a vehicle.

Tractive slip: $$s_t = \frac{r\omega - v_x}{r\omega}$$

Braking slip: $$s_b = \frac{v_x - r\omega}{v_x}$$

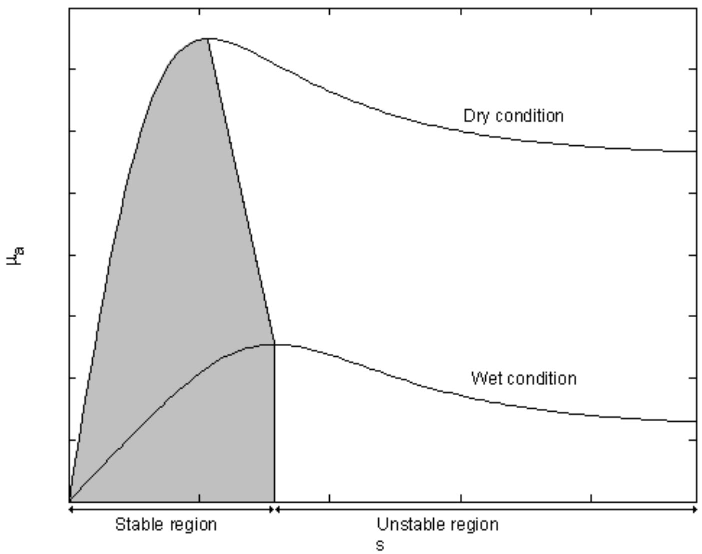
r = wheel radius
ω = rotational speed of the wheel
v_x = longitudinal speed of the vehicle

Qualitative slip curve of a typical rubber tyre of a passenger car

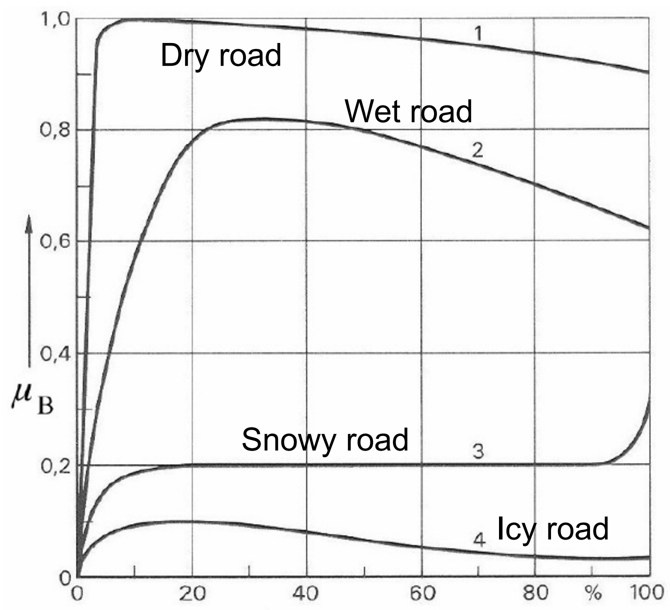


Slip control – Typical slip curves

Brake slip curve of a rail vehicle for different rail conditions.

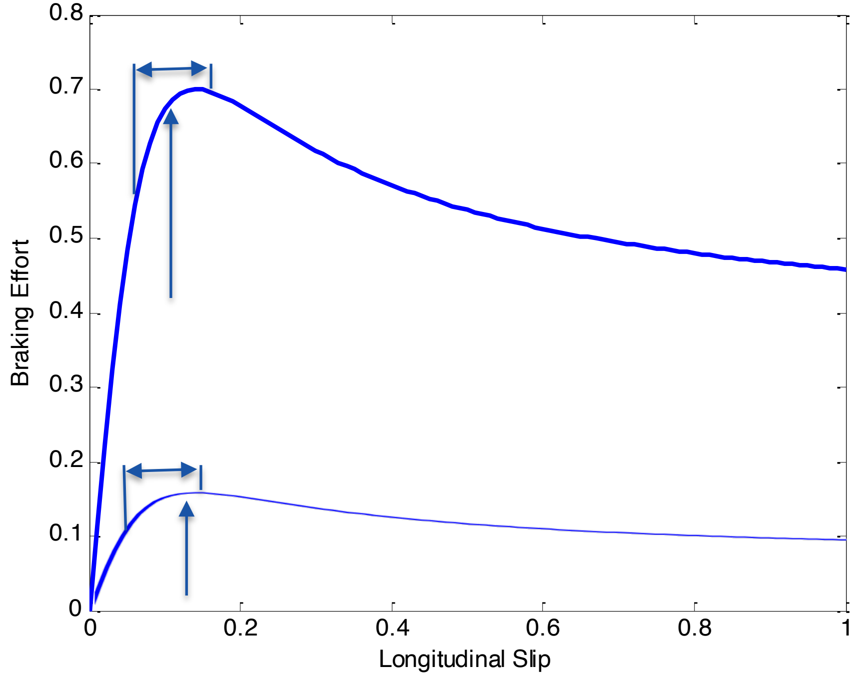


Typical brake slip curves of a rubber tyre for different road conditions



Slip control – Challenges of slip control

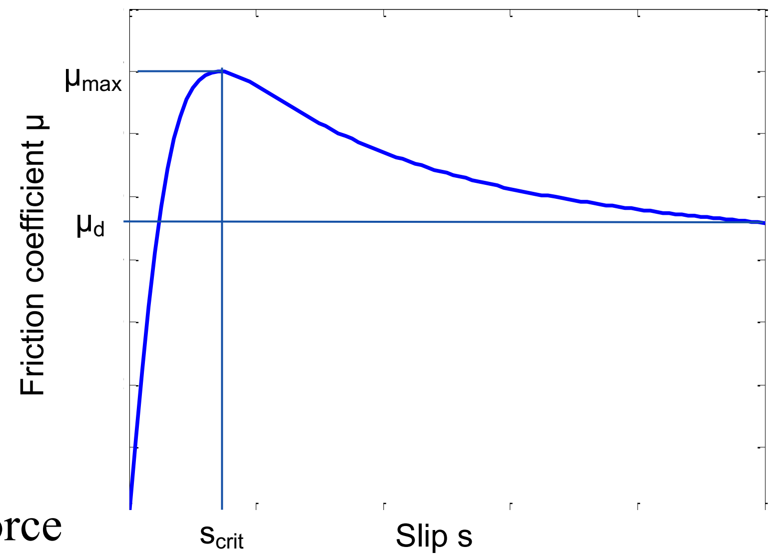
- Quantitative detection of the slip on a wheel, consider case when all wheels are locked.
- Control of the slip within certain thresholds.
- Robust control for all ground characteristics.



Slip control – defining the used friction value

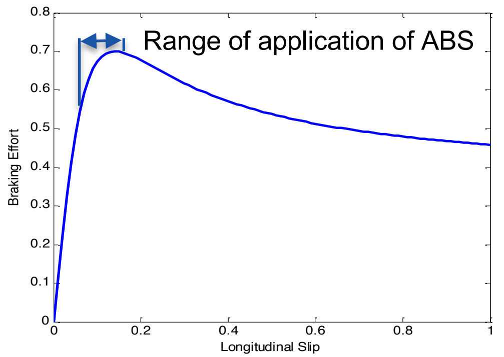
$$\mu_f = \frac{F_{xf}}{N_f} = \frac{F_{xf}}{(1-\lambda)m\cdot g\cdot\cos\alpha+\kappa(F_{xf}+F_{xr})}$$

$$\mu_r = \frac{F_{xr}}{N_r} = \frac{F_{xr}}{\lambda\cdot m\cdot g\cdot\cos\alpha-\kappa(F_{xf}+F_{xr})}$$



Where F_{xf} and F_{xr} is the tractive or braking force on the front and rear axle respectively, λ is the ratio for CoG placement with regards to the wheel base L, α is the road inclination and $\kappa = {}^{h}/_{L}$ is the CoG height over wheel base ratio.

Slip control – Application Anti-lock braking system (ABS)



Introduced already in 1978 in passenger cars.

Main objectives:
a) Maintain stability of the vehicle.
b) Maintain steer-ability during braking.
c) Reduce the stopping distance.

Working principle:

- Prevent wheels from locking while braking by modulation of the brake pressure.
- Each wheel is controlled individually.

Challenge:

- Determine wheel slip.
- Longitudinal vehicle speed is necessary for slip.
- Use existing and cheap sensors.

Slip control – Application
Traction control system (TCS)

First chassis system that could actively provide a brake pressure without a direct driver signal.

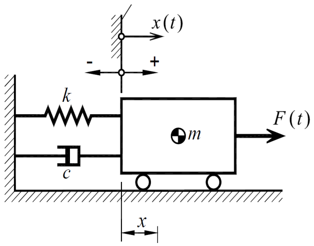
Main objectives: a) Maintain stability of the vehicle.
b) Utilize the available adhesion effectively.

Working principle:

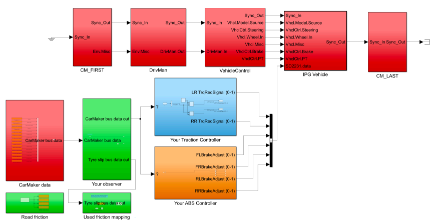
- Prevent wheels from slipping in the high slip areas by actively braking the wheel.
- The highest possible torque can be utilized.
- Each wheel is controlled individually.
- The motor brake is used to reduce the actuations of the brake system.

Assignment of Lab 1 – Simulation setup

Assignment is based on Matlab/Simulink.



1. PID-controller introduction (PID_intro.m)
   - single mass system with a spring and a damper mounted in parallel
   - investigate the different influences of each part of the controller (proportional, integral, derivative).
   - Wheels are frictionless and positive x-direction is given.



2. CarMaker co-simulation model (initial.m; SD2231_Lab1_student.slx)
   - File for Initialising all parameters.
   - Adjustments to the parameters are done in this file.
   - Controllers, Observer and used friction and road friction block (blue, orange and green) is the subsystems that you will work on.
   - Make changes to these blocks only, not the red ones.
   - Driver model: CarMaker driver model
   - Sensor block: only these signals are available in accordance to a real vehicle.
   - Vehicle model: represent Tesla Model S with two electric motors and friction brakes, is a full dynamics model with Magic Formula 5.2 tyres.

Assignment tasks

Task 1: Determine control parameters:

Task 1.a: Derive the equation of motion for the single mass system given and build the transfer function T(s)=(X(s))/(F(s)). Implement the transfer function T(s) in the m-file PID_intro. The m-file will plot the step response of the transfer function without an active controller. Sliders for each control parameter as well as for the mass, spring stiffness and damping coefficient will help you to adjust the step response. Show how you derived the transfer function in the report.

Task 1.b: Use the model to find the control parameters that correspond to Figure 8 for a P-, PD-, PI- and PID-controller. You can use Table 1 to estimate the effectiveness of each controller parameter rather than a pure trial and error method.

Note: please be aware that achieving a relatively similar behavior is enough!

Extra task 1.c*: Analyse the stability of the open loop system and closed-loop systems using your method of choice for all the controllers mentioned above, a total of five analyses.*

Assignment tasks

Task 2: Slip observer

Task 2.a: Implement the tractive and braking slip in the observer block and plot the slip over time. Use the formulation in Equation 1. Only use built in Simulink blocks and not embedded Matlab functions. Show the plot in the report.

Task 2.b: Reflect on the results you presented in Task 2.a, what issues can you see? Propose a solution and ensure that the traction and brake slip is calculated and given when it is supposed to. Show the plot of the adjusted slip observer in the report along with your reflections.

Task 2.c: Save needed data in the Matlab Workspace and implement calculations of the used friction in the initial.m matlab file and plot the used friction (μ) over longitudinal slip (s). Show your equations in the report along with the plot. Present the reference slip that you selected and reflect on why you selected this value.

Assignment tasks

Task 3: Design PID controller

Task 3.a: Add activation logics for the controllers (TCS and ABS). Note that it shall work for all driver inputs (throttle and brake pedal) as soon as traction threshold is reached. Describe under which circumstances the TCS and the ABS will be active.

Task 3.b: Design your own P-, PD-, PI-, PID-controller and compare /discuss the results. You should not use the built in PID blocks, build your own P-, PD-, PI-, PID-controllers using standard blocks.

Task 3.c: Discuss each system and compare them based on system characteristics such as settling time, rise time, overshoot and steady state error. (for each of the controllers; P-, PD-, PI-, PID-controller)

Task 3.d: Is it necessary to use all type of gains for the Traction and ABS controller? Motivate your answer.

Assignment tasks

Task 4: PID controller optimisation

Task 4.a: Present the best controller that has the fastest response, least overshoot and smallest steady state error as well the shortest overall distance.

Extra task 4.b: *Study the controller during changing friction during acceleration and braking event. Do you have to re-tune your model(s) to make your controller handle the disturbance better, if so, show the new tuned PID values and elaborate on the effect between them?*

Task 5: More advanced PID

Extra task 5: *Implement a more advanced PID of your choosing, you are free to use any block in Simulink. Discuss and reflect on your design and if you are able to improve the performance.*

Competition!!!

The winner should reach the **shortest distance** while keeping **minimum steady-state error** between the reference and actual longitudinal slip.

NOTE!

Manage all of your work in one folder which preferably contains **only** one MATLAB and one Simulink file when you want to send them to examiner!

Report writing

- Start working with the report from the start

- Write down each of the steps you have done including the approach, gathered information and the rationale of each of the steps i.e. why you decided to go in a certain direction and why that is better than another way.

- This will help you in the course and it will be easier to finalize the report in time.

- You should search for information on the web and KTH library services, just make sure that you properly cite the work that you use. Search for “IEEE reference guide” on the web for good information on how to format the references.

Teachers of Lab 1

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Computer information
Vehicle Engineering Laboratory

- 15 desktop computers
- The following programs are installed on the PCs:
  - Windows 10
  - Matlab 2018b
  - Adams 2017
  - CarMaker 8.0
- Login name: teknolog
- Login password: osquar

Questions?

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