Longitudinal control

- Design a PID controller for a linear system
- Decompose a coupled nonlinear vehicle model and extract a linear decoupled longitudinal model
- Develop a feedforward controller for longitudinal vehicle control

REFERENCES

Control Theory: https://www.youtube.com/watch?v=lBC1nEq0_nk

PID control

- In the time domain:

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \dot{e}(t)$$

where K_P, K_I, K_D are the proportional, integral and derivative gains

- In the Laplace domain:

$$U(s) = G_c(s)E(s) = \left(K_P + \frac{K_I}{s} + K_D s\right)E(s)$$

$$= \left(\frac{K_D s^2 + K_P s + K_I}{s}\right)E(s)$$

Characteristics P, I, and D gains

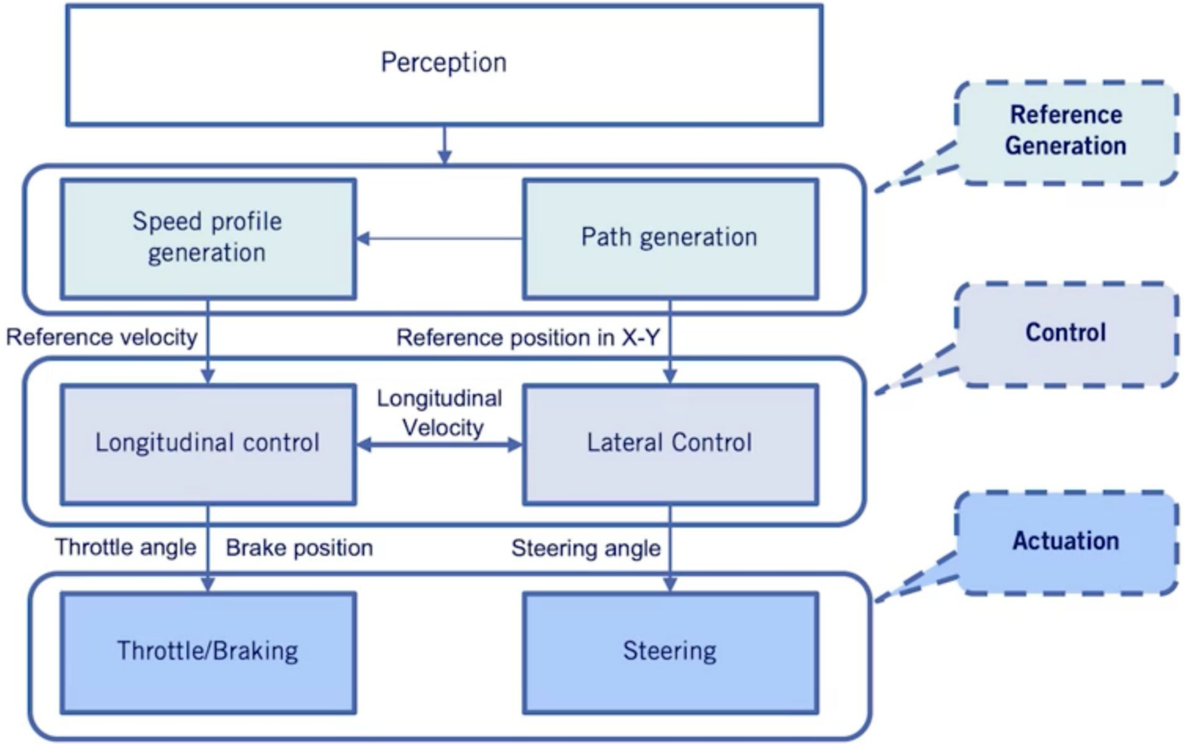
Closed Loop Response	Rise Time	Overshoot	Settling Time	Steady State Error
Increase K_P	Decrease	Increase	Small change	Decrease
Increase K_I	Decrease	Increase	Increase	Eliminate
Increase K_D	Small change	Decrease	Decrease	Small change

Supplementary Reading: Proportional-Integral-Derivative (PID) Control

The previous lecture on Proportional-Integral-Derivative (PID) Controls uses Laplace transforms. If you need to review Laplace transforms, check out these videos on Coursera:

- DifferentialEq: Laplace (Georgia Tech)
- Laplace transform. Calculation of an expectation of a counting process 1 (Higher School of Economics)
- Laplace transform. Calculation of an expectation of a counting process 2 (Higher School of Economics)
- Laplace transform. Calculation of an expectation of a counting process 3 (Higher School of Economics)
- Classical control: Textbook by Prof. Bruce Francis (University of Toronto), covers Laplace Transforms, Bode Diagrams, Nyquist Plots

Architecture of vehicle control strategy



High level controller

- Determines the desired acceleration for the vehicle (based on the reference and actual velocity).

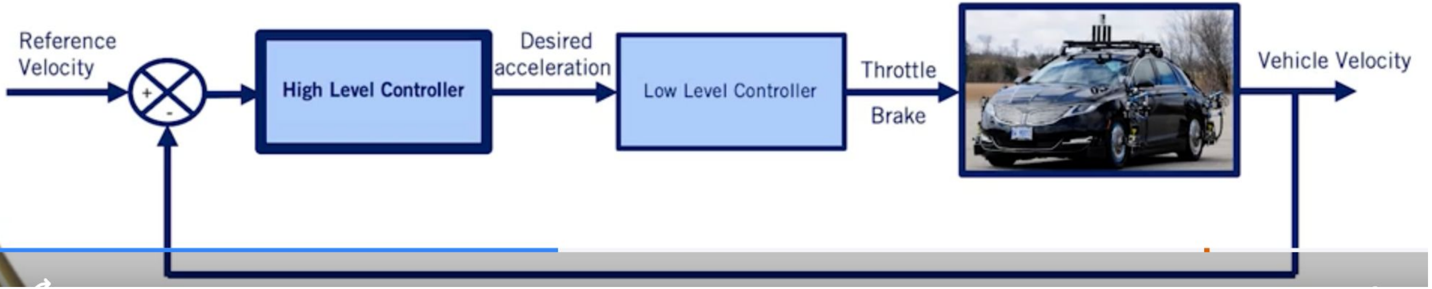
Desired Acceleration

Reference Velocity

Vehicle Velocity

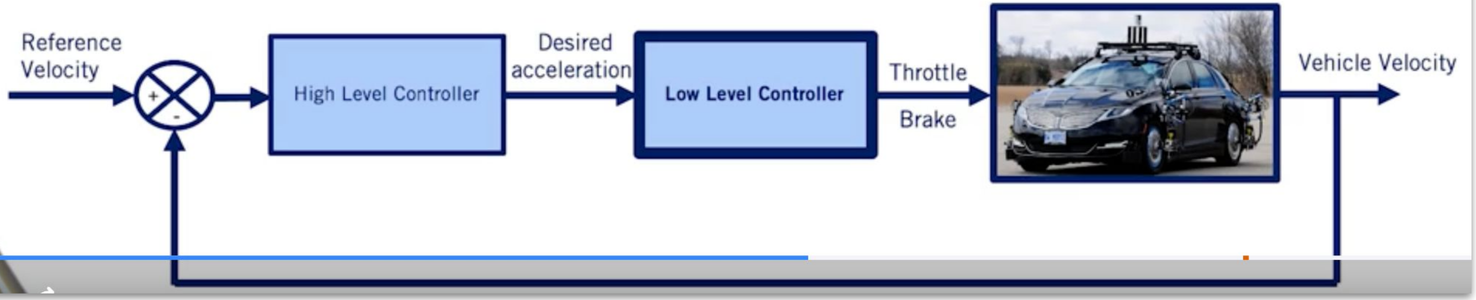
$$\ddot{x}_{des} = K_P\left(\dot{x}_{ref} - \dot{x}\right) + K_I \int_0^t \left(\dot{x}_{ref} - \dot{x}\right)dt + K_D \frac{d\left(\dot{x}_{ref} - \dot{x}\right)}{dt}$$

PID Gains

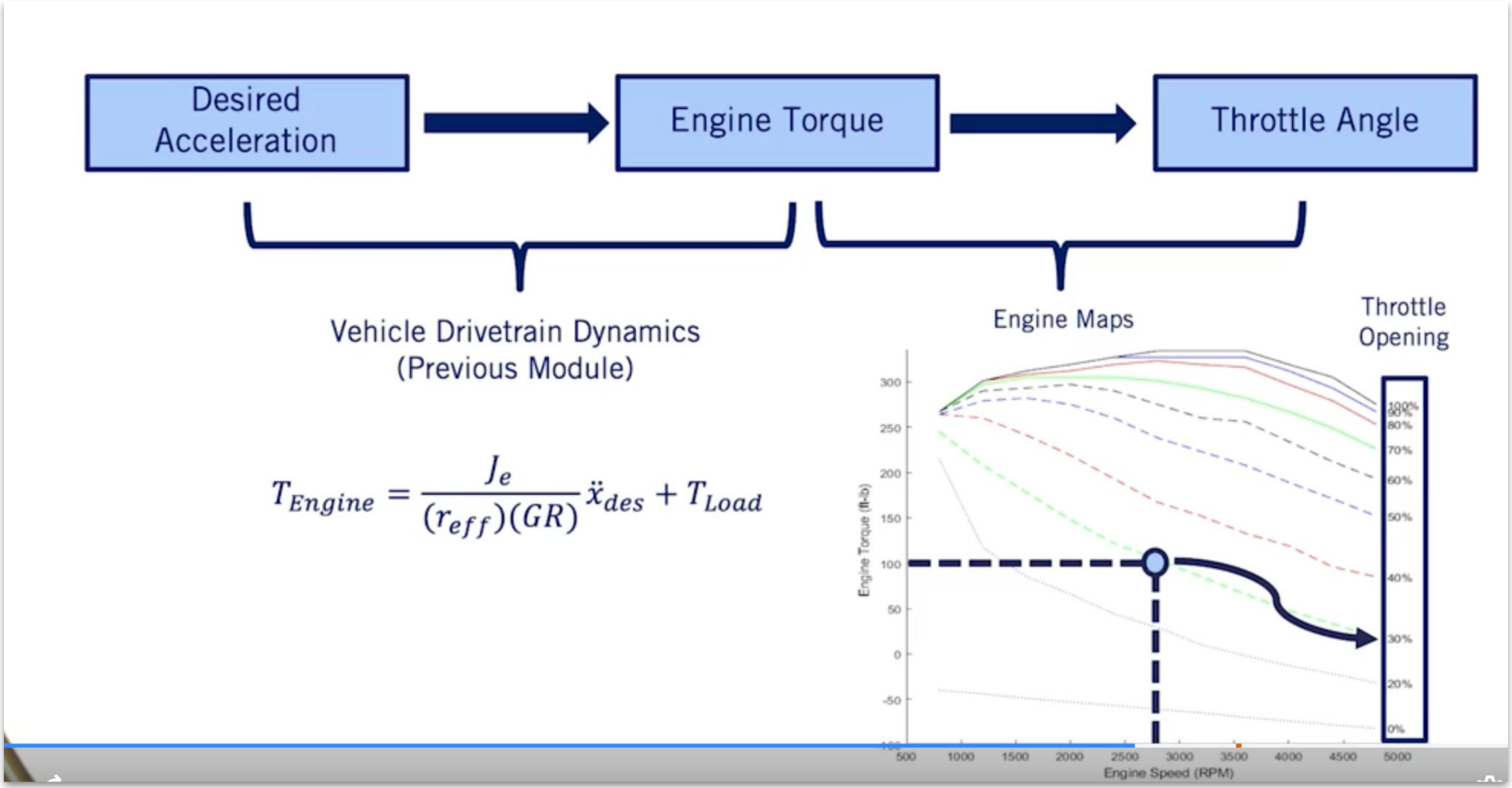


Low level controller

- Lower Level Controller:
  - Throttle input is calculated such that the vehicle track the desired acceleration determined by the upper level controller
- Assumptions:
  - Only throttle actuations is considered (no braking)
  - The torque converter is locked (gear 3+)
  - The tire slip is small (gentle longitudinal maneuvers)



Low level controller



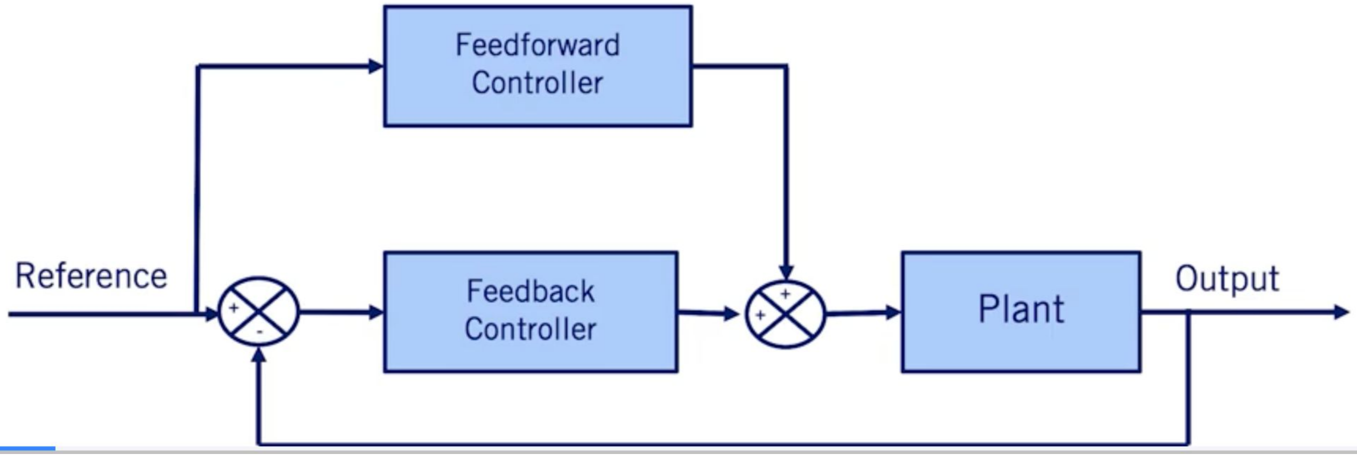
Supplementary Reading: Longitudinal Speed Control with PID

For a deeper dive into longitudinal control, read Chapter 5 (pp. 123-150) in the textbook below:

R. Rajamani, "Introduction to Longitudinal Control " In: *Vehicle Dynamics and Control*, Mechanical Engineering Series, https://link.springer.com/chapter/10.1007%2F0-387-28823-6_5 (2006).

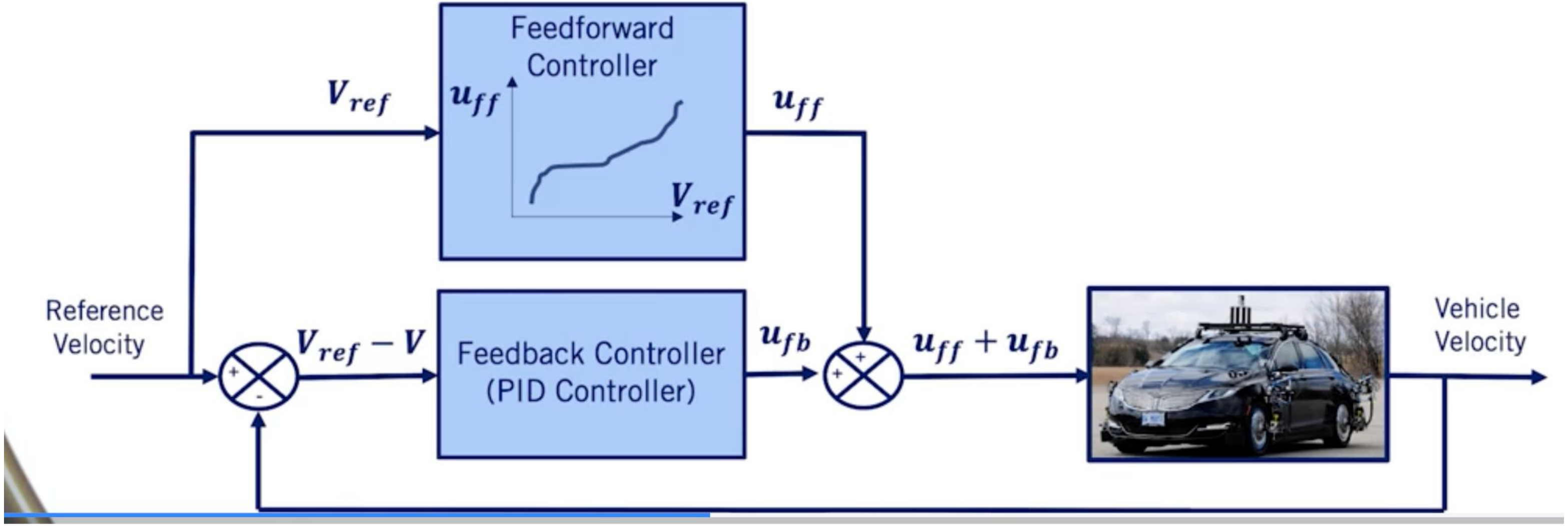
Combine with a feedforward controller

- Feedforward and feedback are often used together:
  - Feedforward controller provides predictive response, non-zero offset
  - Feedback controller corrects the response, compensating for disturbances and errors in the model



Controller actuators

- Actuators (throttle angle):
  - The feedforward controller generates the actuator signal ($\boldsymbol{u_{ff}}$) based on the predefined table and the feedback controller generates the actuator signal ($\boldsymbol{u_{fb}}$) based on the velocity error.



Feedforward table

Reference Velocity

Wheel Angular Speed

$$V_{ref} = r_{eff}\,\omega_w \longrightarrow \omega_w = \frac{V_{ref}}{r_{eff}}$$

Engine Angular Speed

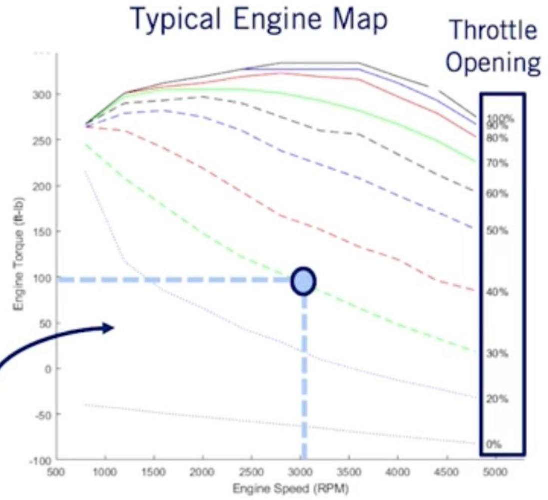
$$\omega_w = GR\,\omega_e \longrightarrow \omega_e = \frac{\omega_w}{GR}$$

Engine Torque

$$T_{Engine} = T_{Load}$$

Throttle Angle

$$\left.\begin{matrix}\omega_e \\ T_{Eng}\end{matrix}\right\} \longrightarrow \Theta_{throttle}$$



Supplementary Reading: Feedforward Speed Control

To learn more about the feedforward speed control, read the PDF below:

Sailan, K., Kuhnert, K.D., "Modeling and Design of Cruise Control System with Feedforward For All Terrain Vehicles", Computer Science & Information Technology (CS & IT). 2013. https://airccj.org/csecfp/library/Search.php?title=MODELING+AND+DESIGN+OF+CRUISE+CONTROL+SYSTEM.

Next

Module 7: Lateral control

https://docs.google.com/presentation/d/1ZkkvW7bkH4KTVpUEcf4SJg2W5gJR93X1fD2nxwR4GKg/edit#slide=id.p