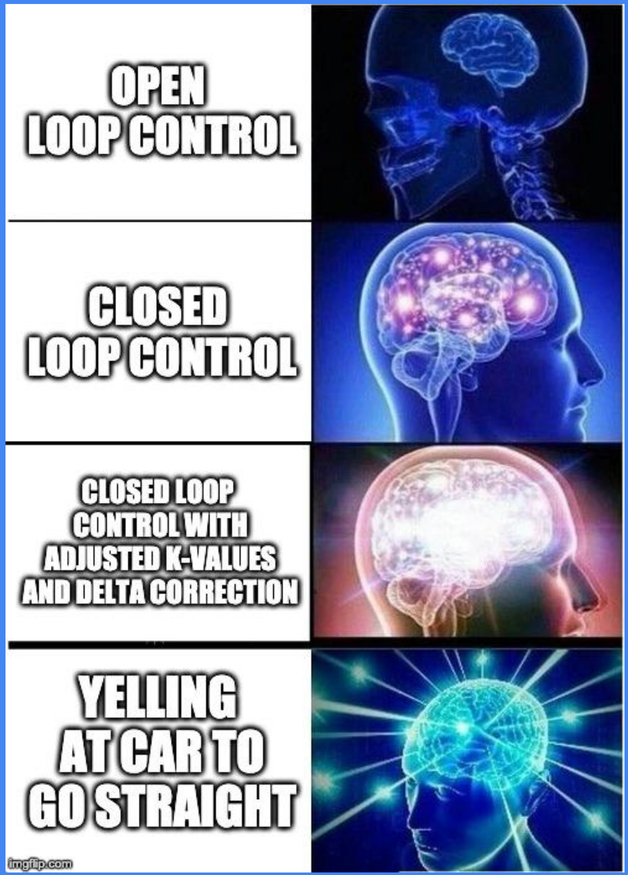
Lab 7: Controls

EECS 16B Fall 2023



Slides: http://links.eecs16b.org/lab7-slides

Lab 7 Overview

- Make your car drive straight!
  - Open-Loop Control
    - Open loop simulation with/without model mismatch
    - Jolt value calculations
  - Closed-Loop Control
    - Simulation + feedback gain f-value tuning
    - Steady-state error correction
- Turning
  - Derive equation
  - Implement turning in Arduino code

System ID → Open Loop Control

$v_L[i] = d_L[i+1] - d_L[i] = \theta_L u_L[i] - \beta_L$
$v_R[i] = d_R[i+1] - d_R[i] = \theta_R u_R[i] - \beta_R$

- Last week, we:
  - knew **u**, measured **v**
  - calculated $\boldsymbol{\theta}_{\mathbf{L,R}}$ and $\boldsymbol{\beta}_{\mathbf{L,R}}$ from least squares
  - Determined operating velocity point **v***
- Opposite problem: given some target **v**, what input **u** do we need?
  - **Open Loop Control:** solve the above equations for u

$$u_L^{OL} = \frac{v^* + \beta_L}{\theta_L} \qquad u_R^{OL} = \frac{v^* + \beta_R}{\theta_R}$$

Problems with Open Loop

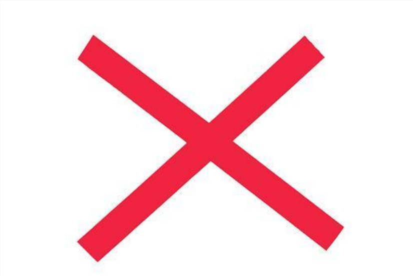
$$u_L^{OL} = \frac{v^* + \beta_L}{\theta_L} \qquad u_R^{OL} = \frac{v^* + \beta_R}{\theta_R}$$

Does open loop work well for systems with disturbances? Why or why not?

Problems with Open Loop

$$u_L^{OL} = \frac{v^* + \beta_L}{\theta_L} \qquad u_R^{OL} = \frac{v^* + \beta_R}{\theta_R}$$

- Will not correct for disturbance/noise (marginally stable)
- Assumes θ, β are the actual θ, β of the wheels
    - Any error will build up, preventing the car from going straight



Closed Loop Intuition

- Introduce an error term that indicates the car's trajectory
  - Negative feedback allows us to correct for disturbance
- Goal: drive this delta to a zero/constant value!

Closed Loop Equations

- Introduce an error term:

$$\delta[i] = d_L[i] - d_R[i]$$

- The wheel/motor models become

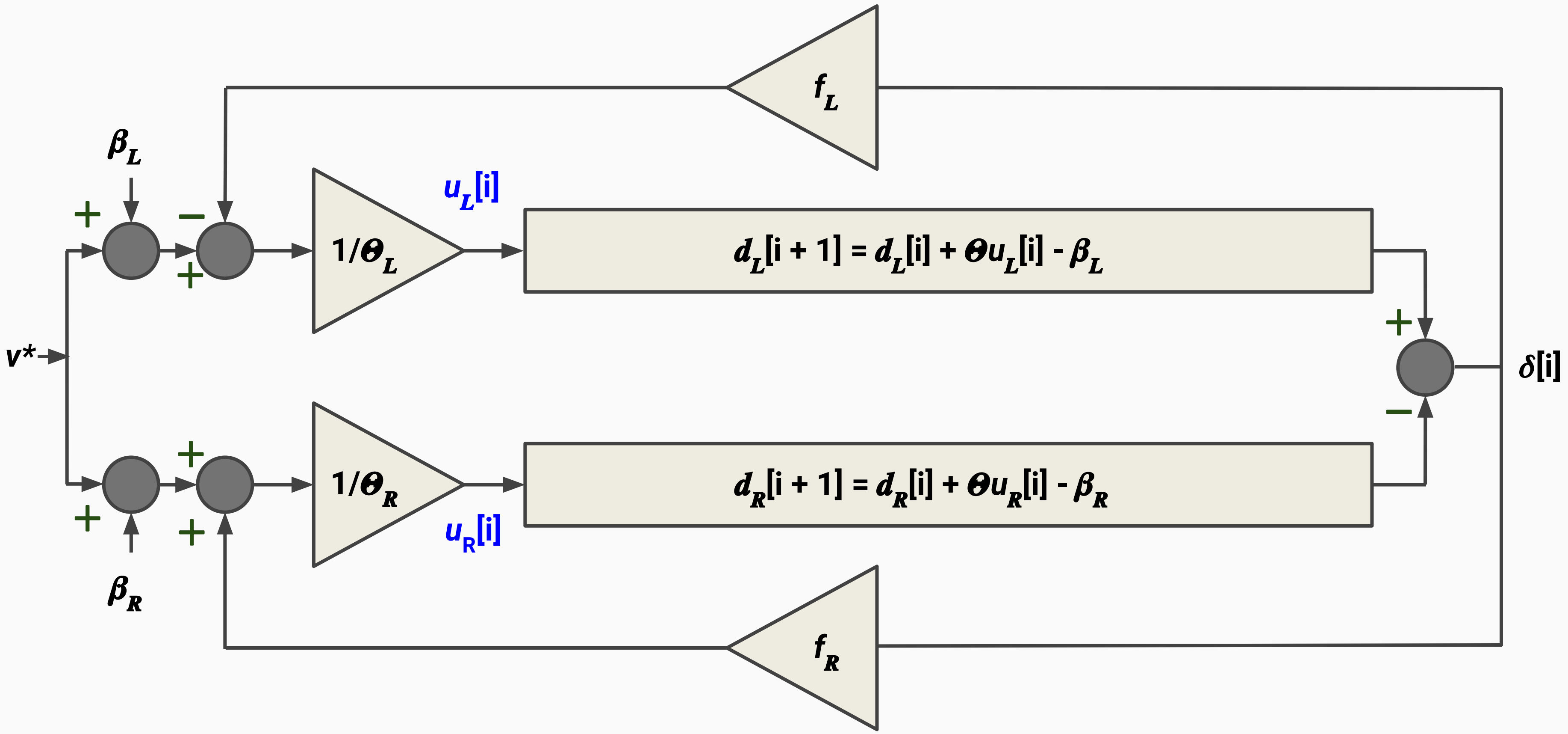
$$d_L[i+1] = d_L[i] + \theta_L u_L[i] - \beta_L \mathbf{- f_L \delta[i]}$$
$$d_R[i+1] = d_R[i] + \theta_R u_R[i] - \beta_R \mathbf{+ f_R \delta[i]}$$

Note: Convention is that f > 0

$$u_L[i] = u_L^{OL} - \frac{f_L}{\theta_L}\delta[i] \qquad u_R[i] = u_R^{OL} + \frac{f_R}{\theta_R}\delta[i]$$

$$u_L^{OL} = \frac{v^* + \beta_L}{\theta_L} \qquad u_R^{OL} = \frac{v^* + \beta_R}{\theta_R}$$

Closed Loop Visualization for finding u



Review: Closed-Loop Control

Open-Loop Equations

$$u_L^{OL} = \frac{v^* + \beta_L}{\theta_L}$$

$$u_R^{OL} = \frac{v^* + \beta_R}{\theta_R}$$

Closed-Loop Equations

$$u_L[i] = u_L^{OL} - \frac{f_L}{\theta_L}\delta[i]$$

$$u_R[i] = u_R^{OL} + \frac{f_R}{\theta_R}\delta[i]$$

$$\delta[i] = d_L[i] - d_R[i]$$

Closed Loop Analysis

- What's the error after one step?
  - $\delta[i+1] = d_L[i+1] - d_R[i+1]$
  - $\delta[i+1] = v^* - f_L\delta[i] + d_L[i] - (v^* + f_R\delta[i] + d_R[i])$ ← Plug in for d[i+1]: *v[i] = d[i + 1] - d[i]*
  - $\delta[i+1] = \delta[i]\,(1 - f_L - f_R)$ ← Simplify
    - This is of the discrete system form $\delta[i+1] = \lambda\,\delta[i]$, so $\boldsymbol{\lambda}$ **= (1 - fL - fR)**
- Stability Analysis:
  - $|\lambda| < 1$: system is stable (error decreases over time)
  - $|\lambda| > 1$: system is unstable (error increases over time)
  - $\lambda < 0$: system is oscillatory (overcorrection, f-values are too large)

Exploiting Delta for Turning

- What happens during turning?
  - One wheel moves more than the other
  - + delta → dL > dR → turn right
  - - delta → dL < dR → turn left
- Idea: Add artificial offset value to δ[i]
  - Car “thinks” its turning
  - “corrects” it by driving δ → 0
  - Naive implementation: add a constant offset?

Closed-Loop Equations

$$u_L[i] = u_L^{OL} - \frac{f_L}{\theta_L}\delta[i]$$

$$u_R[i] = u_R^{OL} + \frac{f_R}{\theta_R}\delta[i]$$

$$\delta[i] = d_L[i] - d_R[i]$$

Exploiting Delta for Turning

- Naive implementation: add a constant offset?
  - Car tries to turn very suddenly
  - Large offset -> wheels leave controllable range
  - Isn’t really “aesthetic”
    - car will turn once and then drive straight rather than sweeping an angle

Closed-Loop Equations

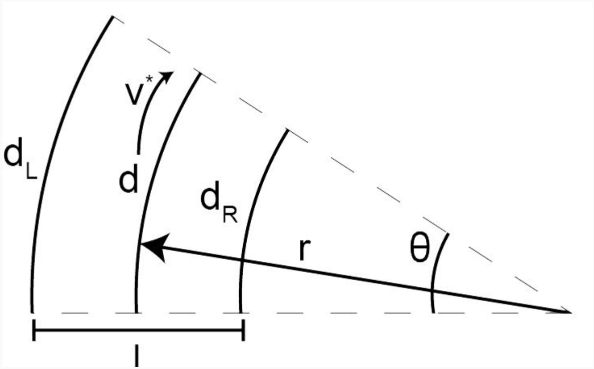
$$u_L[i] = u_L^{OL} - \frac{f_L}{\theta_L}\delta[i]$$

$$u_R[i] = u_R^{OL} + \frac{f_R}{\theta_R}\delta[i]$$

$$\delta[i] = d_L[i] - d_R[i]$$

Exploiting Delta for Turning

- Goal: gradual, circular turn
  - delta is a distance function!
  - Idea: add offset as a variable dependent on time
- In the case of a circular turn, what should δ[i] be at time i?
  - Function of **r** (turn radius), **l** (car width), **v***, and time **i**
  - Use arc length formula!
  - Relate distance to velocity and time
  - Check your derivation with staff



Implementing turning.ino

- Code the function for $\delta[i]$ you found
  - Control loop and the data collection have different periods
  - Account for different sampling rates of data collection and controller
- (Optionally) apply a straight correction for any lingering turning due to mechanical errors

Mic Board Verification

- As a final step, verify that your biasing circuits and front-end circuitry still work as expected.
  - we will be using the mic board next week for the SVD/PCA lab!

Lab 7 Checkoff

- Our definition of “straight” is based on the floor tiling in Cory:
    - Inside Cory 125 (1x4 tiles)
    - Outside Cory 125 (3 x 11 on black)
    - Side entrance hallway, from the pink line to the red line (2 x 7 tiles)

Common Bugs

- Double check all equations!
  - For both closed loop and turning, one term is positive and on term is negative
- If a wheel jolts and stops moving:
  1. Double check that all pins (motor and encoder) you are using are correctly defined in the Arduino code
  2. Rerun encoder tests from System ID to make sure encoders are still working
- If motors are no longer running, rerun the encoder tests

Tips and Common Errors

- Don't guess f-values, this will take you forever!
    - Make educated decisions on how to change your f values from iterations of testing.
    - If you car is turning left, how should you change f_L and f_R to fix it?
- Data is stored in RAM, just like last lab, so make sure you keep the 9V plugged in when you plug the USB into your computer
- You can manipulate the turn radius and run times (in ms!) of the turning sequence
- Ensure you've replaced v* with v* / m ONLY in delta_reference function
- Do not cut the power supply cable and cause a firework. please.

Important Forms/Links

- Help request form: https://eecs16b.org/lab-help
- Checkoff request form: https://eecs16b.org/lab-checkoff
- Extension Requests: https://eecs16b.org/extensions
- Slides: http://links.eecs16b.org/lab7-slides-sp23
- Anon Feedback: https://eecs16b.org/lab-anon-feedback
- Lab Grades error: https://links.eecs16b.org/lab-checkoff-error