E11 – Autonomous Vehicles

Feedback Control

[Diagram of a control system with labels: Set point, K(s), PIC, Valves, pH Device, pH Meter, Disturbance, Output]
This week’s lab:
  - line-following robot
  - completed in teams (within same lab session)

After fall break:
  - No lab week of 10/21
  - Line-following competition! (in class – Wednesday 10/23)

Game logistics and guest lectures:
  - 10/28: Game Kickoff!
  - 11/11: Game Scrimmage (in class)
  - 11/25: Final Game Competition!! (Monday, 5:30pm – Galileo)
The door code is: 4-3-12 (Parsons B171)
Stay on our side of the curtain!
Keep lab door open when you’re in it – make sure it’s closed and locked when you leave, and turn lights off
Don’t remove anything from the lab
Do not touch other people’s robots/stuff
Keep the lab clean and organized – throw away garbage, put stuff back where it belongs. The lab should look as good or better as when you got there!
You may leave your robots/kits in the cubby holes in lab
Turn off all soldering irons when leaving.
Outline

- Control Loops
- Developing Control Algorithms
Outline

- Control Loops
  - Open loop
  - Closed loop
- Developing Control Algorithms
Open Loop Control

- Output activated according to preset rules
  - Example 1: sprinklers turn on for 5 minutes every morning, independent of current weather conditions
  - Example 2: a heater turns on for 10 minutes every hour independent of current temperature.

http://www.waterworksbradenton.com/sprinklers.htm
Output is dependent on and affects inputs

- **Example 1**: sprinklers turn on every morning until a desired moisture level is reached (as determined by a moisture sensor)
- **Example 2**: a heater turns on until the thermostat reaches a desired temperature (as determined by a thermocouple)
- Represent a system, inputs, and outputs

**Block Diagrams**

Inputs → System → Outputs

- Mapping function
- Data, variables, signals, ...

- Inputs
- System
- Outputs
Block Diagrams

- Represent a system, inputs, and outputs

- **Inputs**: Desired states or sensors measurements
  - E.g. Thermocouple, distance sensor, phototransistor, reflectance sensor, force plate

- **Outputs**: Signals sent to actuators
  - E.g. Heater, motor, data collector
Open Loop System
  - i.e. no loop
Closed Loop System:
- Output affects input
- Sensor measurements used as input
Detailed System

- Open Loop
  1. Controller
  2. Actuator
  3. Plant
Detailed System

- Closed Loop
  1. Controller
  2. Actuator
  3. Plant
  4. Sensor
Control Example

- **Controller:**
  - Receives input from plant, controls actuator (e.g. thermostat)
- **Actuator:**
  - Heater/Cooler
- **Plant:**
  - A room
- **Sensor:**
  - Temperature Sensor (Thermocouple?)
Outline

- Control Loops
  - Open loop
  - Closed loop
    - Bang-bang control
    - Proportional control
- Developing Control Algorithms
**Feedback Control**

- **Bang-Bang Control**
  - The system checks the input (via a sensor), if it’s not a desired value, the controller turns on actuator
  - Otherwise, the controller turns off actuator
Other Feedback Control Method

- **Proportional Control:**
  - The system responds proportional to the error:

  \[
  \text{error} = (\text{desired value} - \text{measured value})
  \]
Example:
- Adjusting hot and cold faucets to get the desired temperature
- If the temperature is much colder than desired, the hot water faucet is opened a lot (proportional to desired-measured temp)
- If the temperature is slightly colder than desired, the hot water faucet is only opened a little (proportional to desired-measured temp)
In General

Calculate Error

\[ e = x_{des} - x \]

Calculate Control effort

\[ u = K_p e \]
Example:

- Drive Robot to a distance 10cm from wall.

\[
e = x_{\text{des}} - x
\]

\[
= 10 - \text{IR Sensor Measurement}
\]

\[
K_p e = 100
\]

\[
\text{motor Signal} = \min(K_p e, 255)
\]
Outline

- Control Loops
- Developing Control Algorithms
  - What are algorithms?
  - How to represent algorithms
  - Example algorithms
Algorithm:

- A sequence of steps needed to accomplish a goal
- Algorithms are frequently represented using flowcharts
Control Algorithms

- **Flow Chart Primitives**

  - Process
    (something the system does)

  - Decision

  - Logical Flow

  - Read Temperature

  - Temperature < 70 F?
    - NO → Turn Heater Off
    - YES

  - Turn Heater On
Problem solving
1. State goal in words
2. Create algorithm
3. Code algorithm
4. Test / debug
5. Repeat steps 2-4 until satisfied
Open Loop Control:

- Design an algorithm that turns the buzzer on twice a second for 10 ms. Draw a flowchart of your algorithm.
Algorithm Example 1

- Turn buzzer on
- 10 ms passed? NO
- Turn buzzer off
- 490 ms passed? NO
  YES
Algorithm Example 2

- Closed Loop Control
  - Use proportional control to design an algorithm that turns the heater on depending on the difference between the desired and detected temperature.
Algorithm Example 2

Detect Temperature

NO

Detected < Desired Temp?

YES

Turn heater on proportional to (Desired - Measured Temp)
Algorithm Example 3

- Closed Loop Control
  - Use proportional control to drive your robot up to an object as fast as possible without hitting it. (When your robot reaches the object, it should stop 😊)
Algorithm Example 4

Detect Distance

Detected Distance > 0?

NO → Examine Object

YES → Move motors Forward at speed proportional to Measured Dist
Open Loop Control:
- System function does not affect the inputs

Closed Loop Control:
- System function affects the inputs

Types of Feedback Control:
- Bang-bang control: the system turns on (does something) until a desired value is reached
- Proportional control: the system responds proportional to the error (desired – measured)

Algorithm:
- Sequence of steps needed to accomplish a goal

Flowchart:
- Graphical representation of algorithm