AEM 4321 / EE4231
Automatic Control Systems

Course Overview

Outline

- Course Objectives
- Applications of Control
- Examples: Cruise Control and Aircraft Autopilots
  - Terminology
  - Block Diagrams
- Summary

Course Objectives

- Develop an understanding of classical control techniques and the basic properties of feedback.

- Feedback
  - Use a sensor to measure the system behavior
  - Compare measured behavior with desired behavior
  - Take actions based on this comparison

- Feedback enables many advanced technologies.

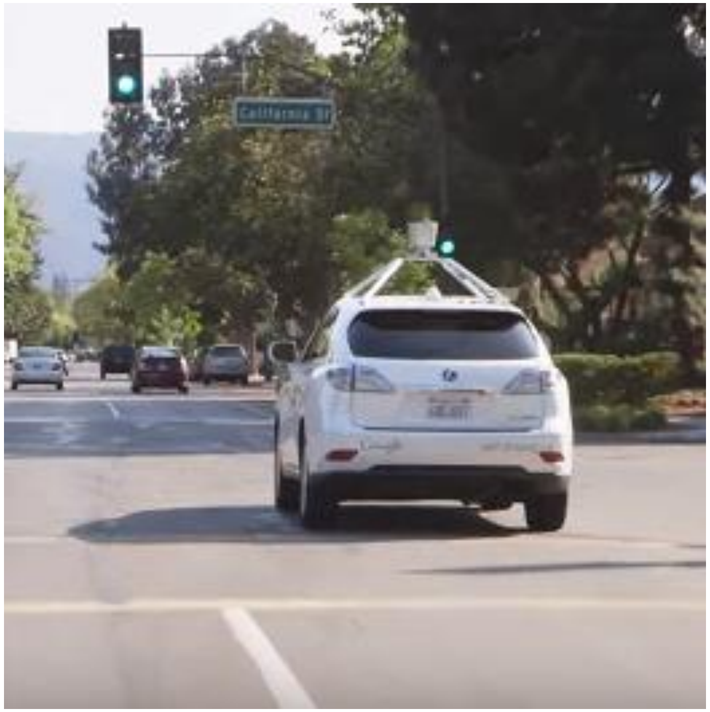
Reusable Rockets: Blue Origin and SpaceX

First Landing by Blue Origin on 11/23/2015

Links

http://arstechnica.com/science/2015/11/blue-origin-sticks-rocket-landing-a-major-step-toward-reusable-spaceflight/
https://www.youtube.com/watch?v=9pillaOxGCo
https://www.youtube.com/watch?v=igEWYbnoHc4

Self-Driving Cars (Google, Uber, and Many Others)



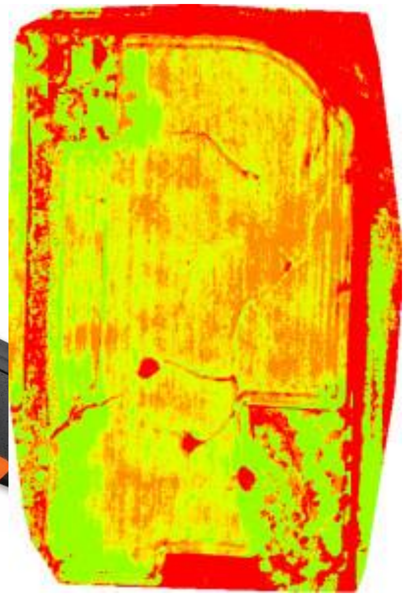
Google's Car in Mountain View, CA

Uber's Volvo XC90 (coming to Pittsburgh, PA)

Links

http://www.bloomberg.com/news/features/2016-08-18/uber-s-first-self-driving-fleet-arrives-in-pittsburgh-this-month-is06r7on
https://www.google.com/selfdrivingcar/
https://www.youtube.com/watch?v=bDOnn0-4Nq8

Uninhabited Aerial Systems (UAVs) / Drones



Sentera Phoenix 2
(Precision Agriculture,
Road/Pipeline Surveillance, etc)

DJI Phantom 4
(Cinematic Photos, Building
Surveillance, etc)

Links

https://www.youtube.com/watch?v=tJB9g_ne23U
https://sentera.com/phoenix-2/
https://www.dji.com/product/phantom-4
https://www.youtube.com/watch?v=JJPSSqMQajA

Athletic Robotics

Bike Riding Robot

Raffaello D'Andrea's Ted Talk

These two examples are for "fun" but similar techniques have many "real" applications (e.g. Kiva Systems robots for automated warehouses).

Links

https://www.youtube.com/watch?v=mT3vfSQePcs
https://www.ted.com/talks/raffaello_d_andrea_the_astounding_athletic_power_of_quadcopters?language=en

Example: Automotive Cruise Control

Objective: Use the engine throttle to track a desired speed specified by the driver

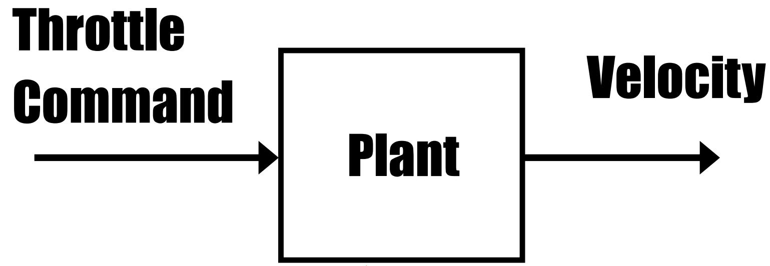
User interface

Vehicle

Block Diagrams

Systems represented by blocks with inputs/outputs

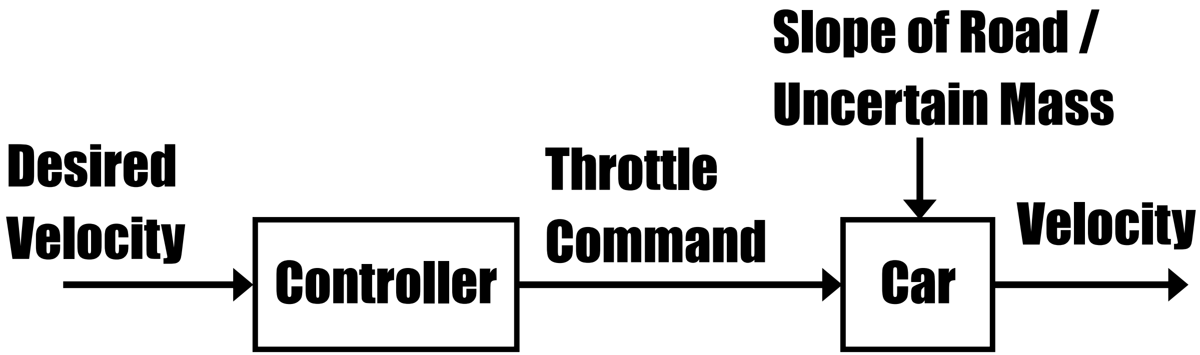
- "Hide" the dynamics
- Interconnect blocks for more complex systems



The plant (car) is the system being controlled.

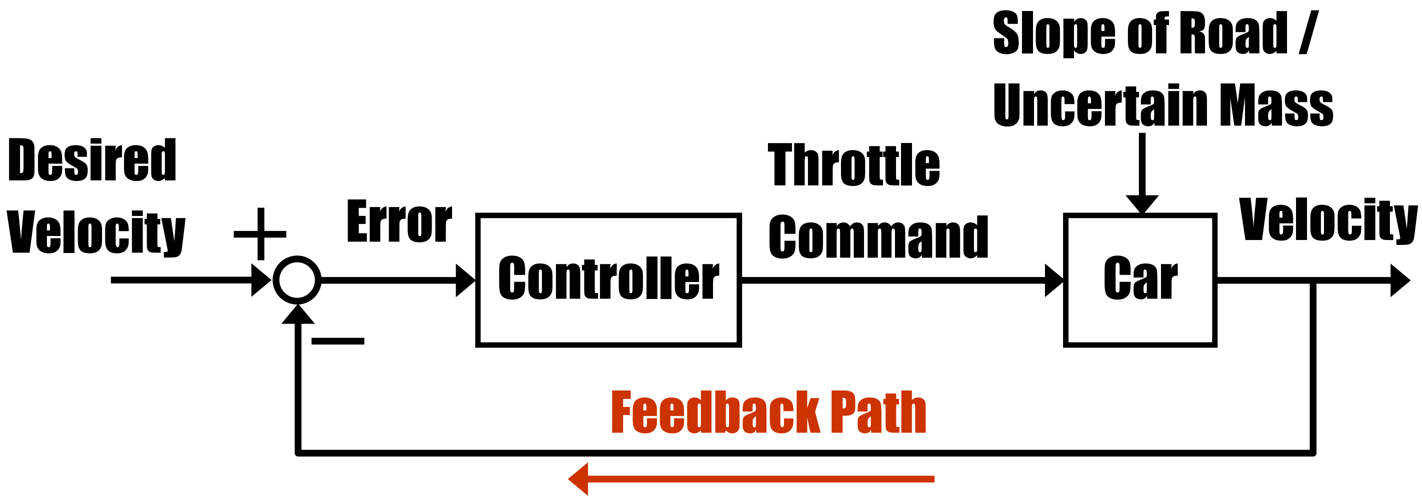
Open Loop

- Open Loop: Compute an engine throttle angle based on the desired velocity.
- Issue: Incomplete knowledge of the car dynamics
  - Uncertain mass, e.g. different #'s of passengers
  - Varying environment conditions, e.g. hills and wind
  - Imprecise models for complex effects, e.g. engine dynamics and tire forces.

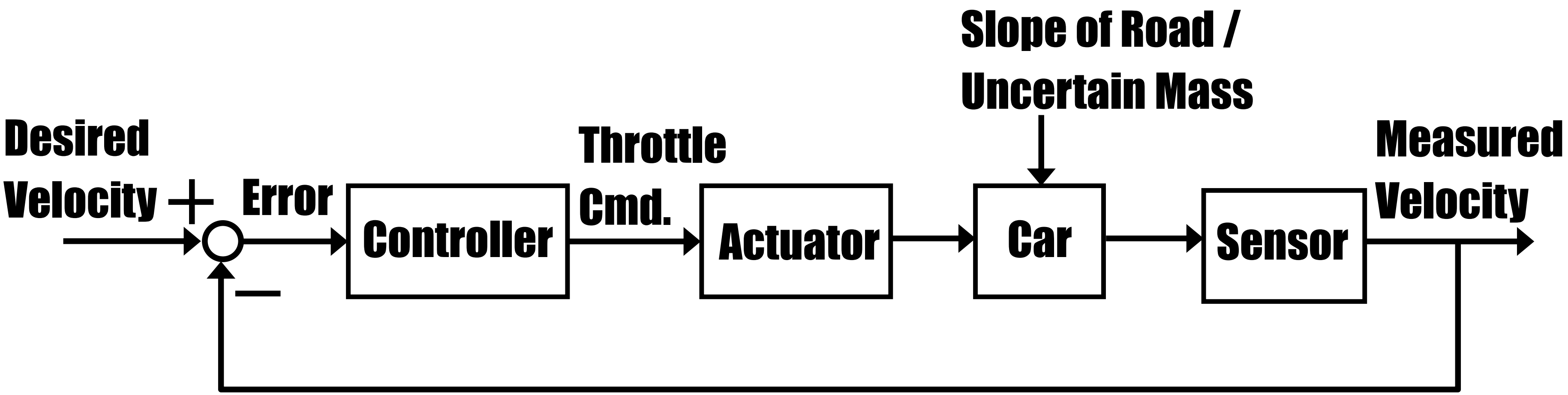


Closed Loop / Feedback

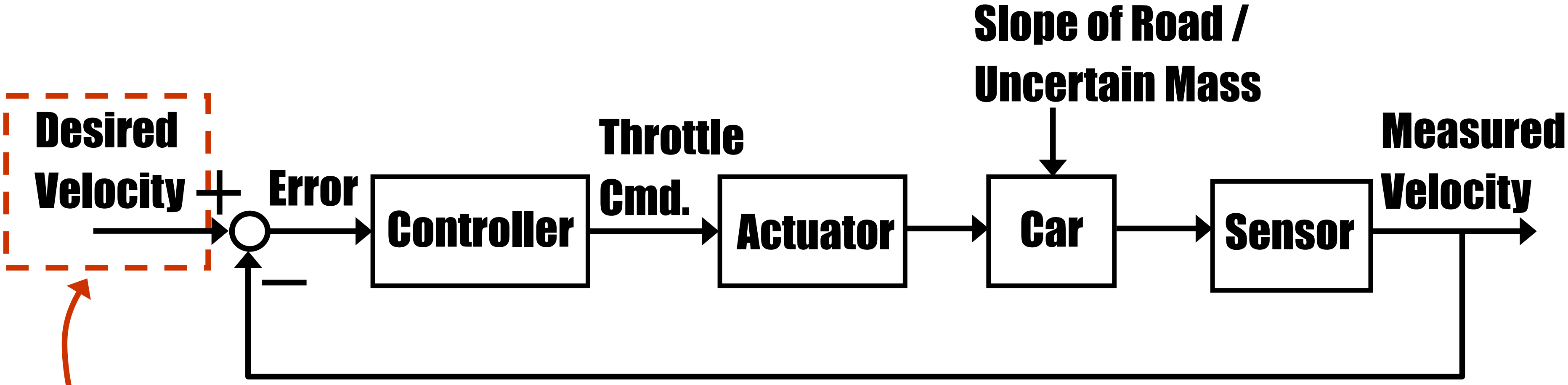
- Closed Loop: Update the throttle command based on a measurement of the current vehicle speed.
- Feedback is the basic principle used to control the system despite our incomplete knowledge.
- The use of feedback involves tradeoffs
  - Stability, speed of response, sensor noise rejection

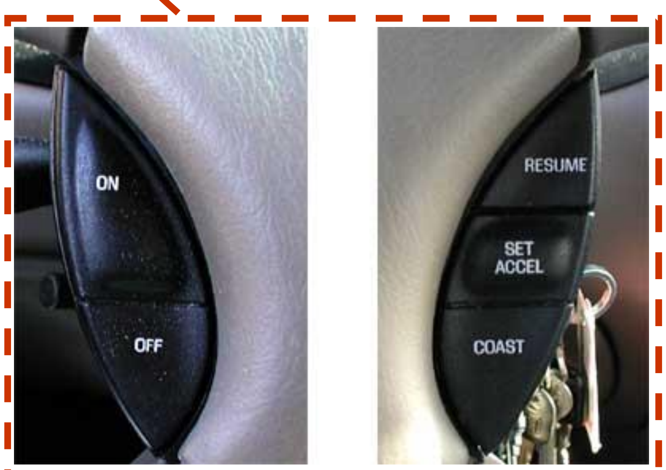


Cruise Control Block Diagram



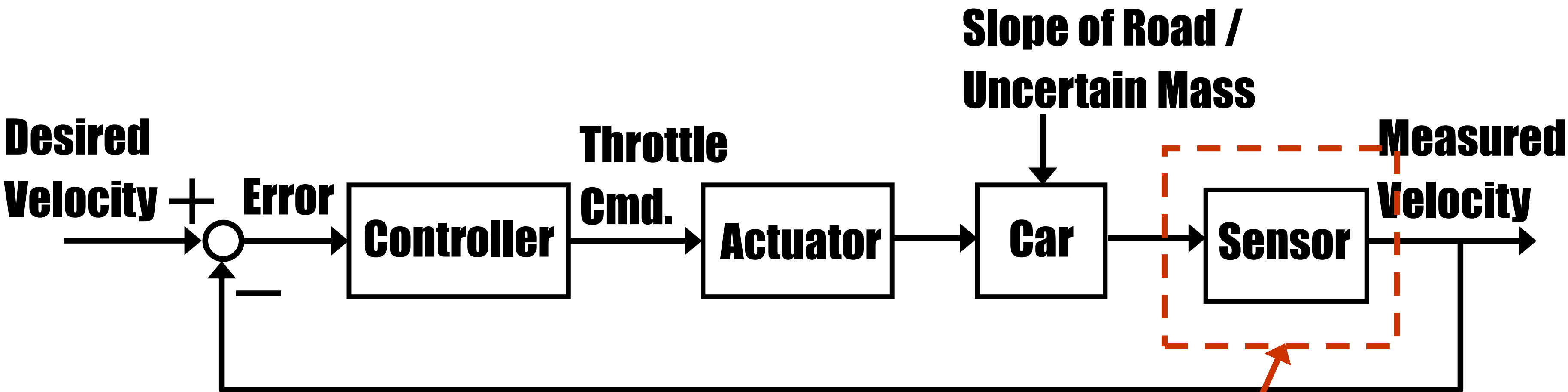
Reference Command

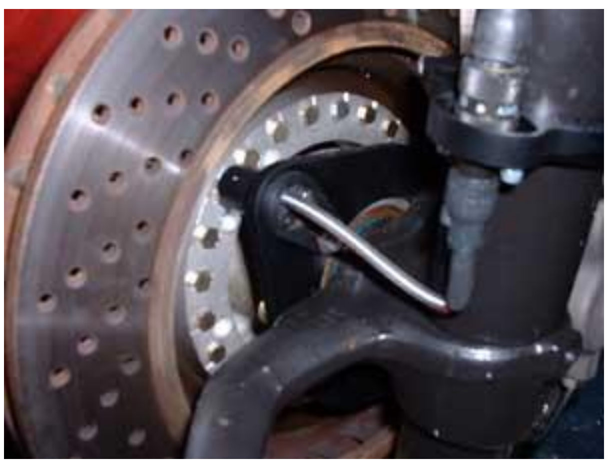




The reference (desired velocity) is the desired condition for the system.

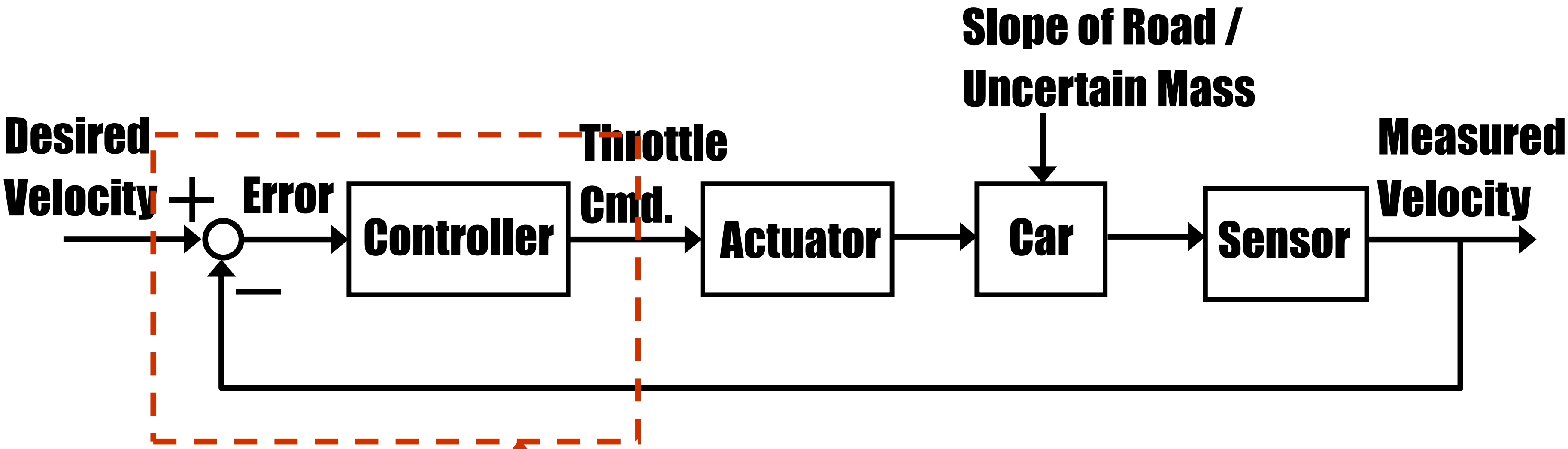
Sensor



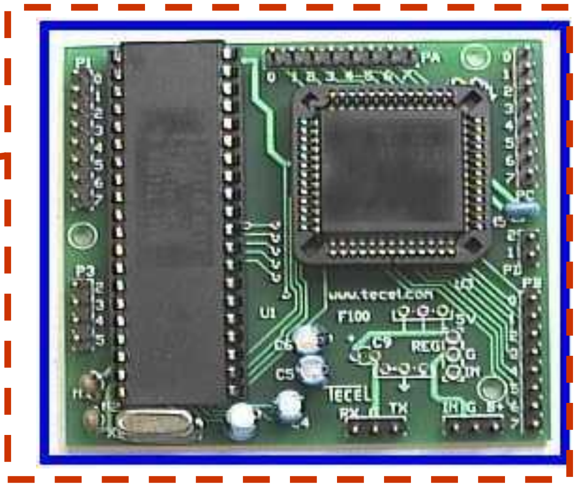


The sensor (wheel speed sensor) is a device used to measure the behavior of the plant.

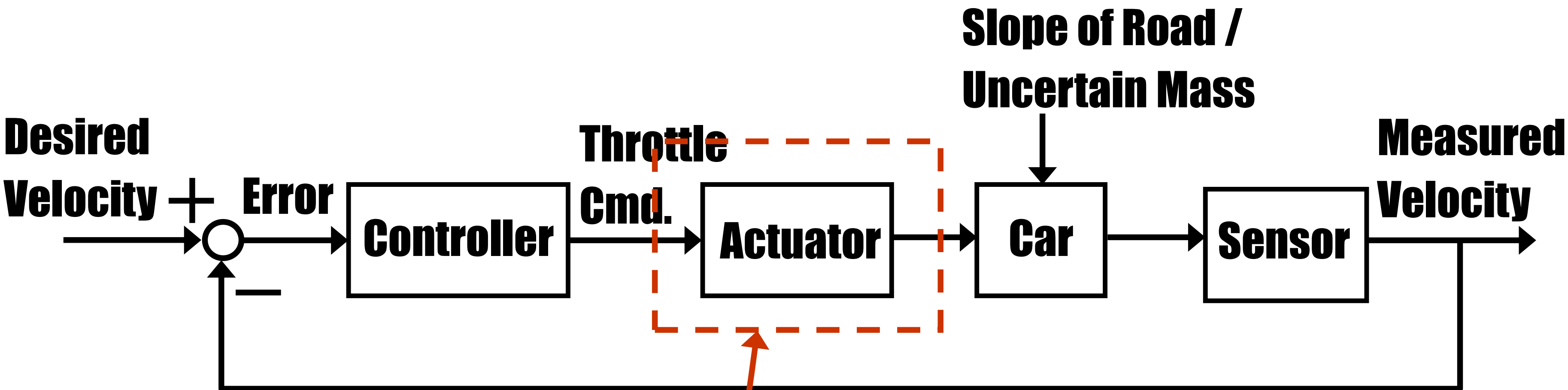
Embedded Processor



The algorithm computations are
are done on an embedded processor.

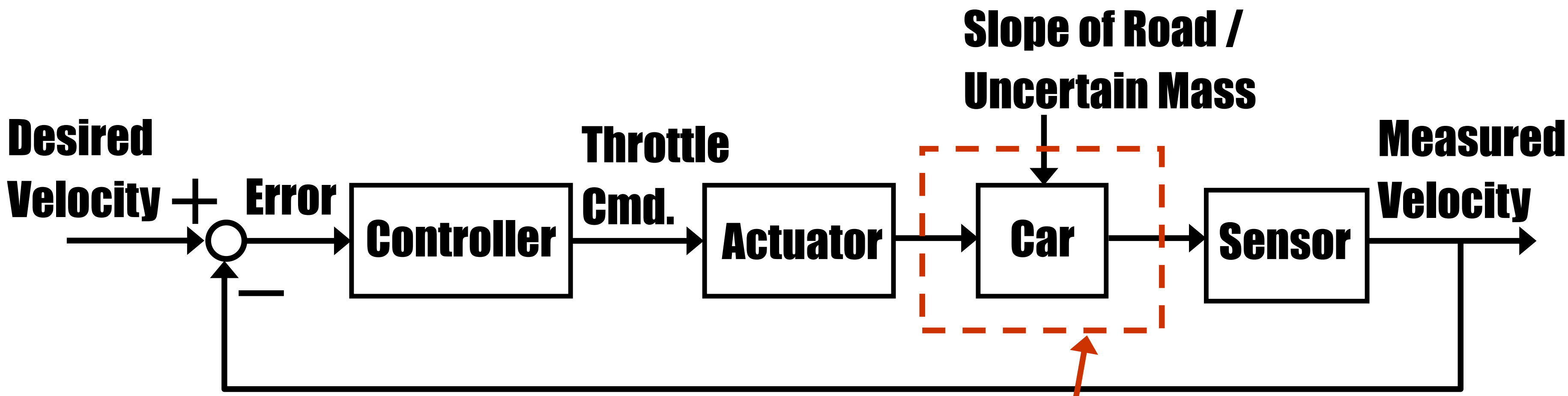


Actuator



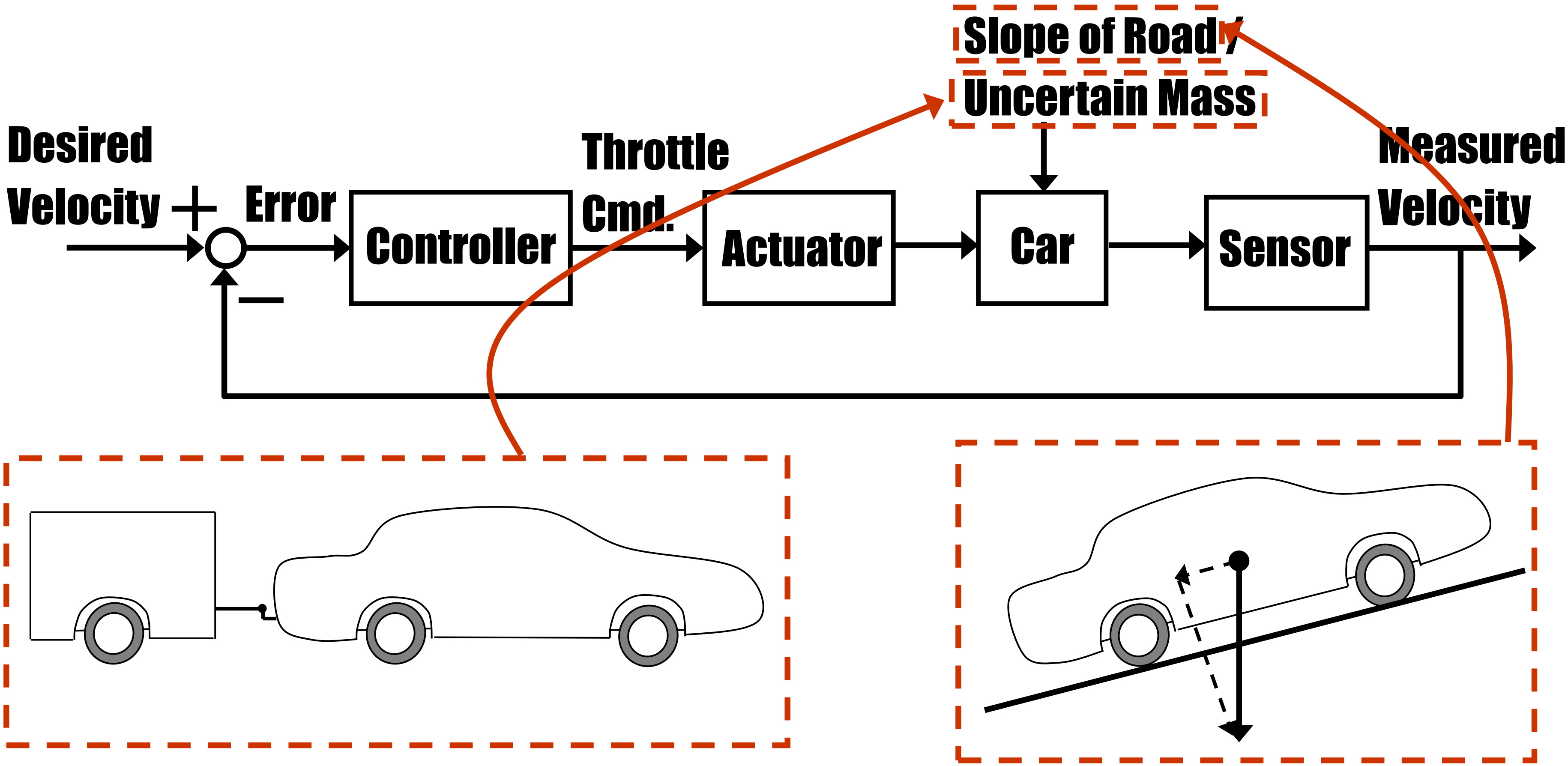
The actuator (throttle motor) is a device used to control the plant.

Plant

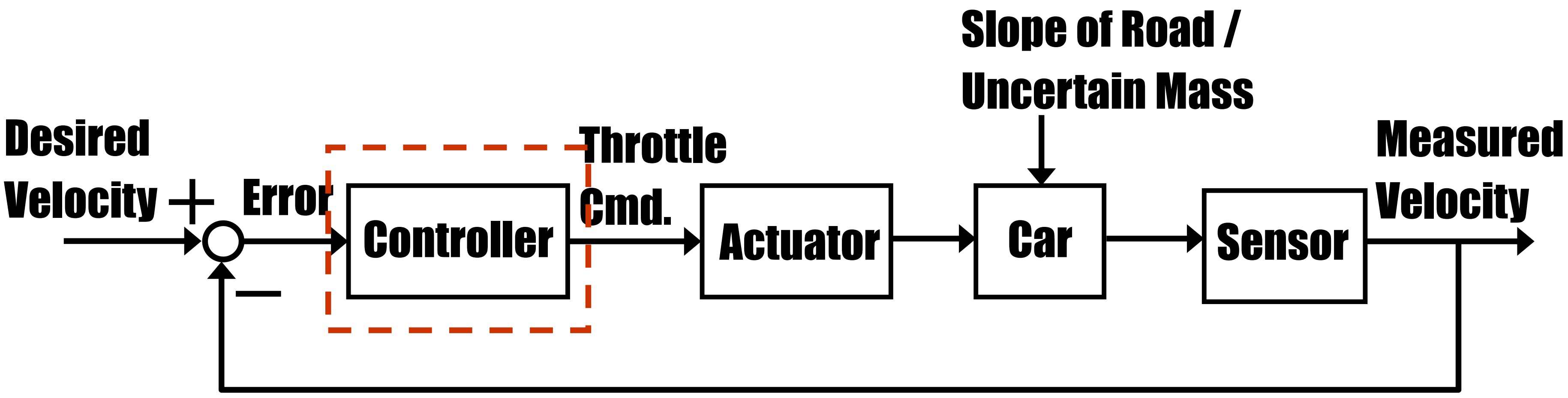


The plant (car) is the system being controlled.

Uncertainties / Disturbances

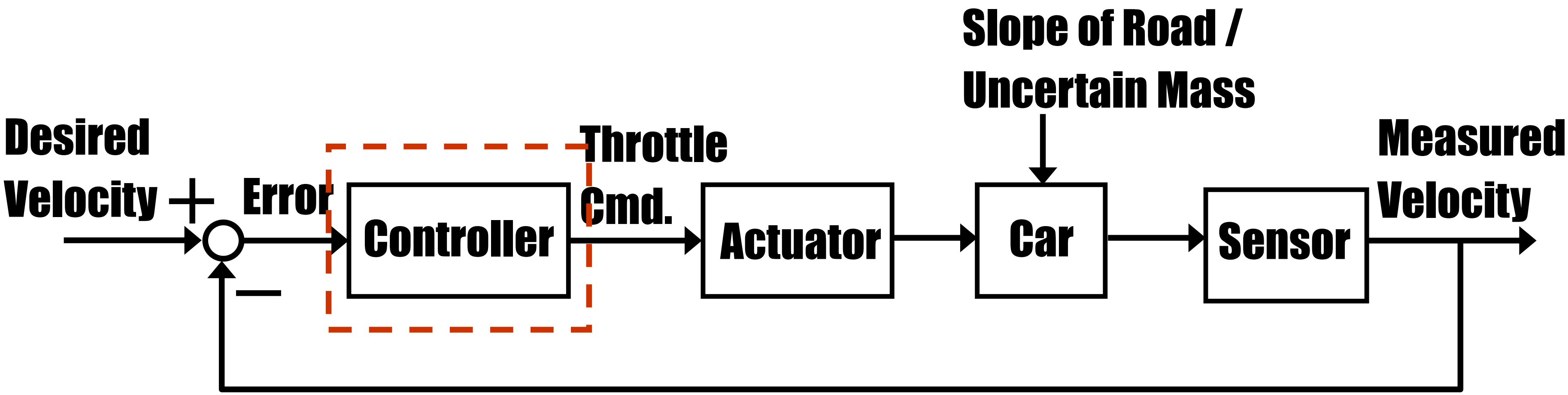


Control Design



- Objective: Maintain the desired velocity
- Considerations:
  - Transient response (rise time, overshoot)
  - Changes in desired velocity
  - Driver comfort (control effort)
  - Disturbances, model uncertainty, sensor noise

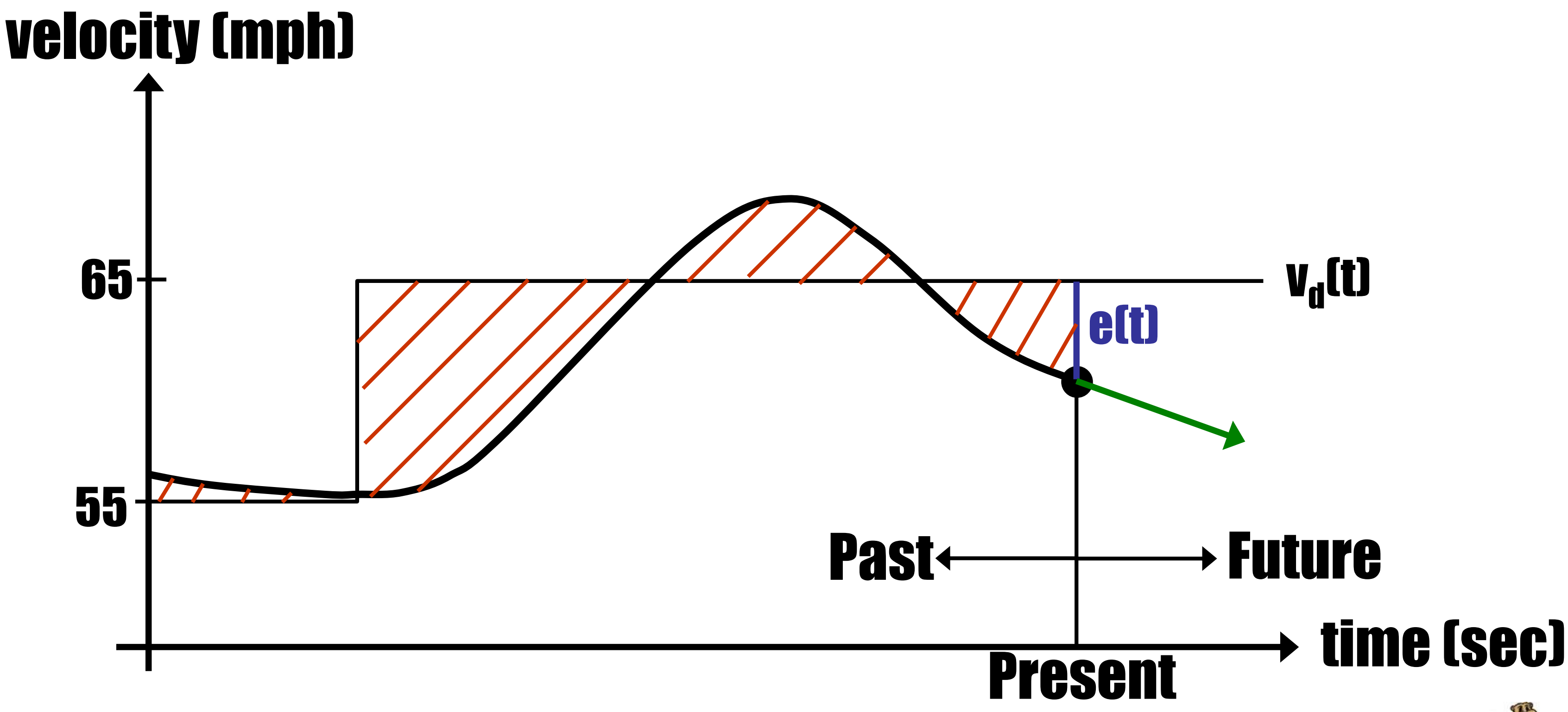
Control Design



- Design Process
  1. Model the system: Differential equations
  2. Design the control algorithm
  3. Analyze and simulate: Theory + MATLAB
  4. Implement the controller and experiment
  5. Iterate

Proportional-Integral-Derivative (PID) Control

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{de(t)}{dt}$$



Example: Commercial Fly-by-Wire

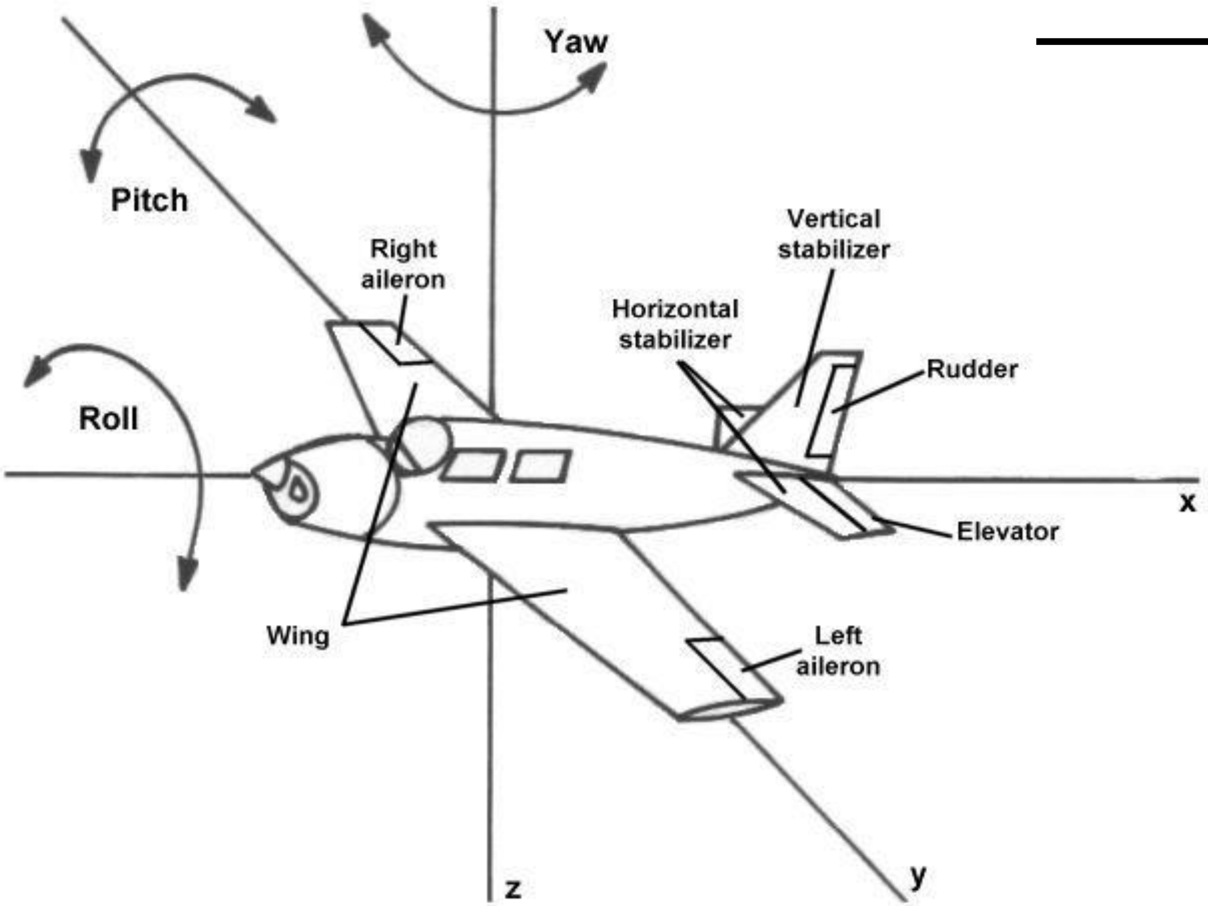
Boeing 787-8 Dreamliner

- 210-250 seats
- Length=56.7m, Wingspan=60.0m
- Range < 15200km, Speed< M0.89
- First Composite Airliner
- Honeywell Flight Control Electronics

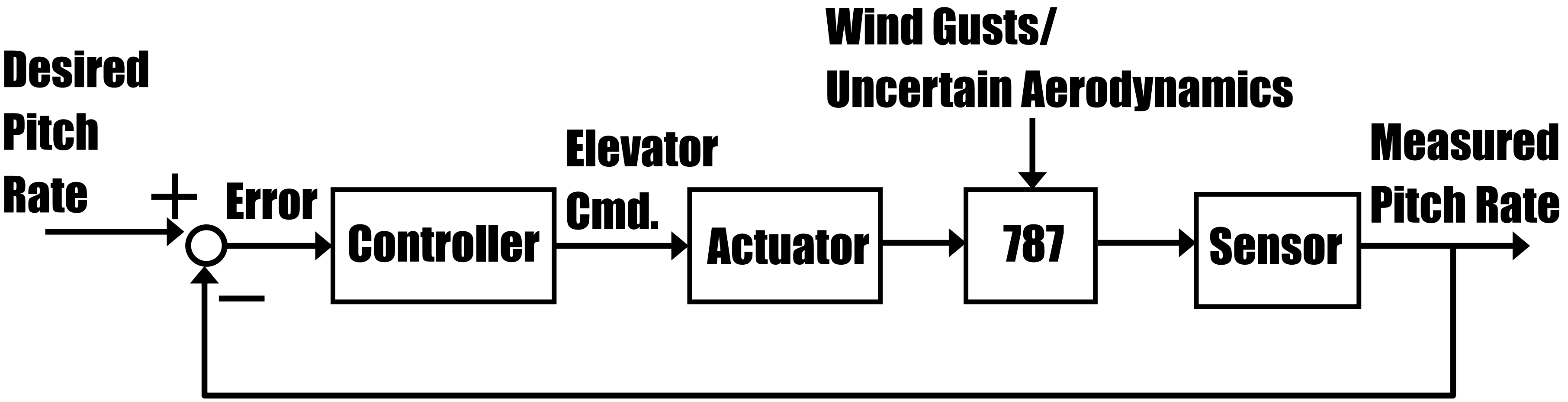
Boeing 777-200

- 301-440 seats
- Length=63.7m, Wingspan=60.9m
- Range < 9700km, Speed< M0.89
- Boeing's 1st Fly-by-Wire Aircraft
- Ref: Y.C. Yeh, "Triple-triple redundant 777 primary flight computer," 1996.

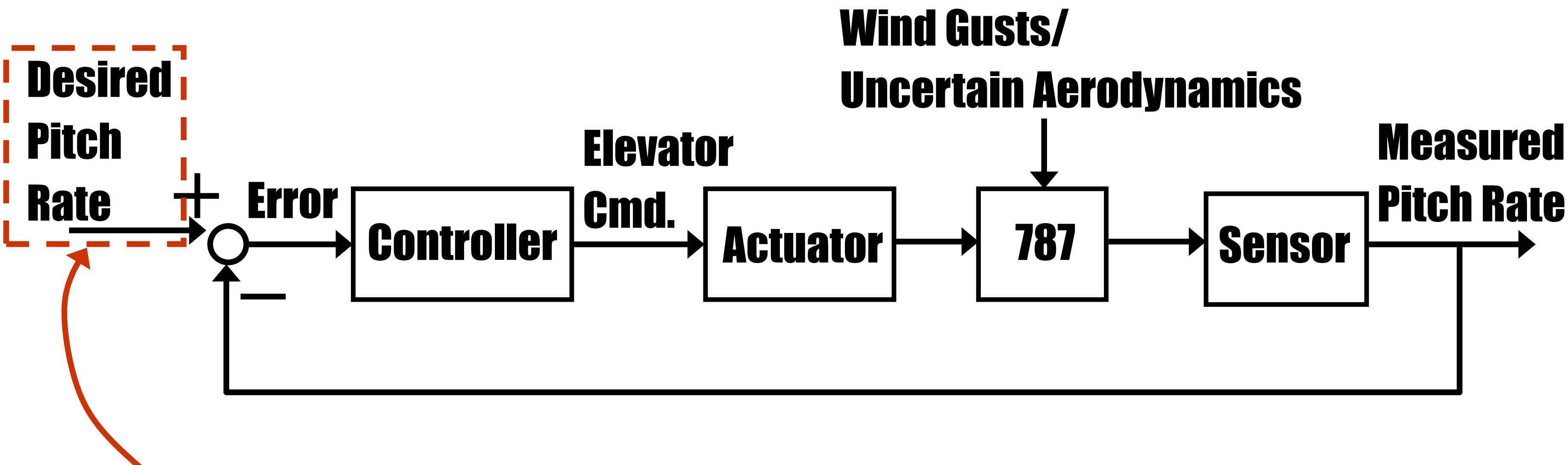
Basic Aircraft Control



Block Diagram: Pitch Rate Control

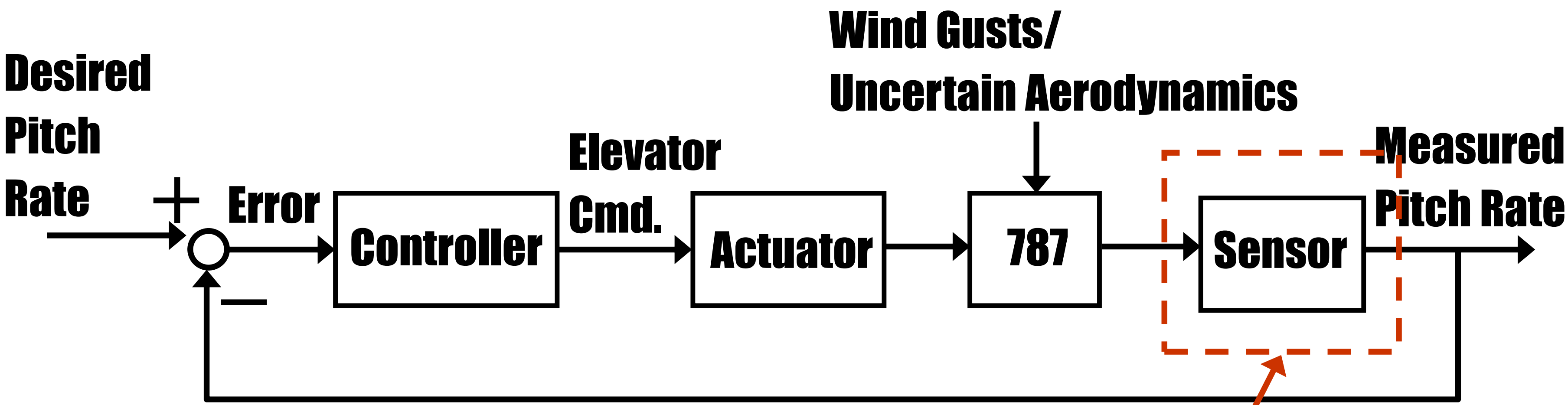


Reference Command



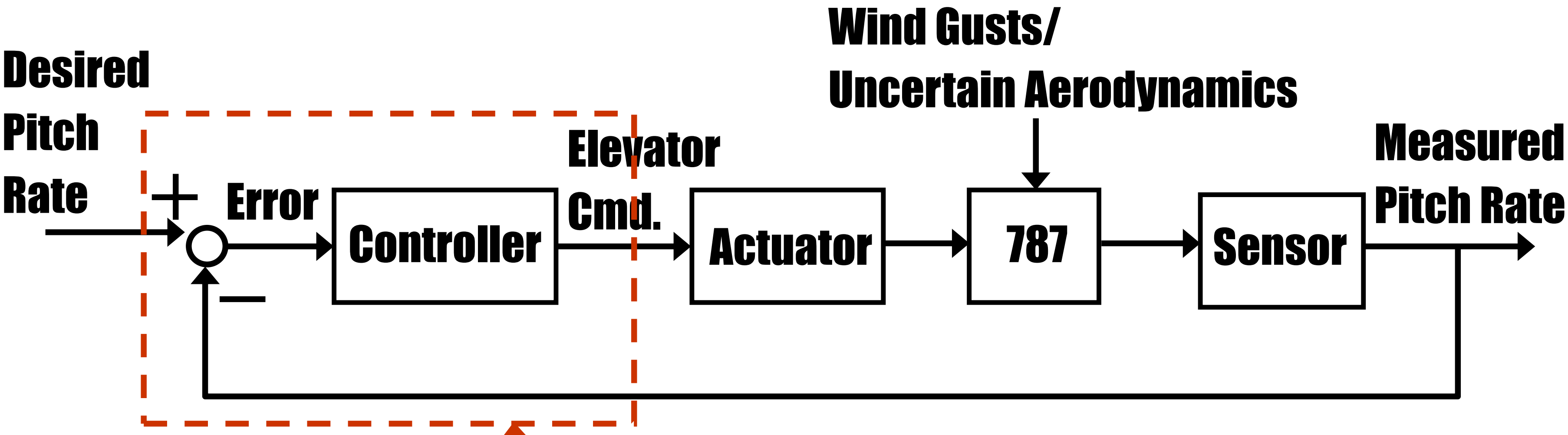
The pilot pulls on the column to specify a desired pitch rate.

Sensor



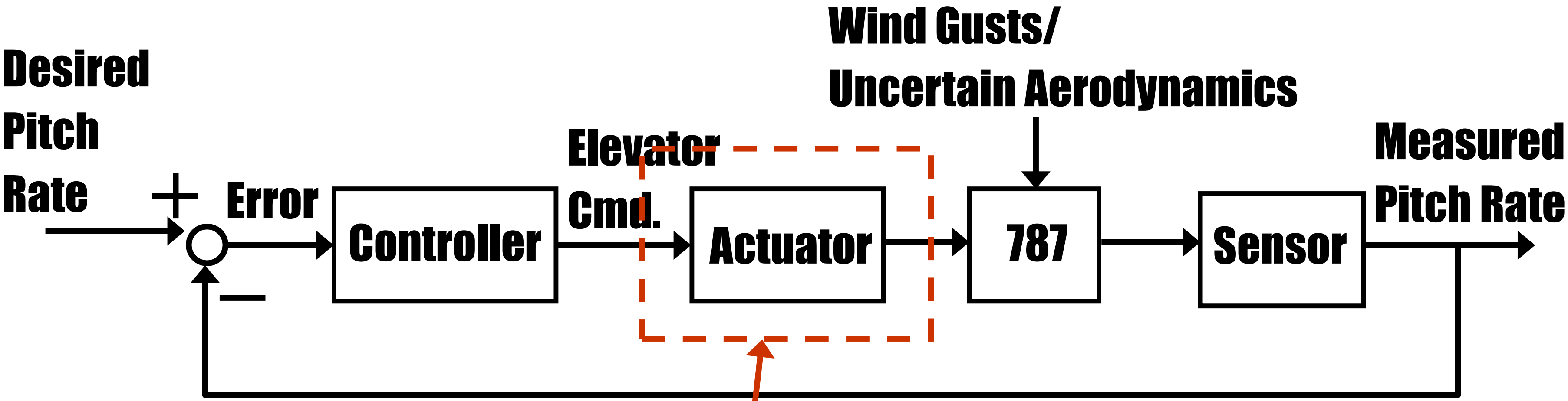
A gyroscope is used to measure the aircraft pitch rate

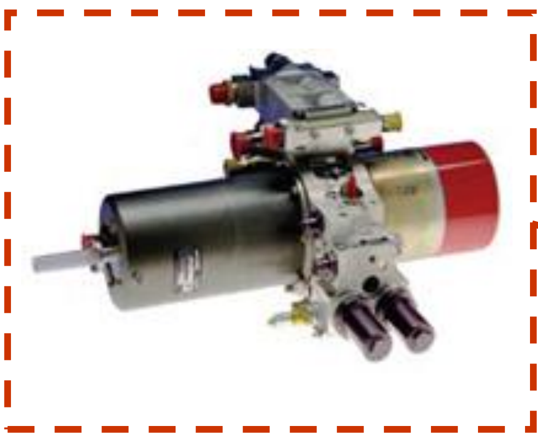
Redundant Computers



The algorithm computations are done on multiple redundant computers for reliability.

Actuator

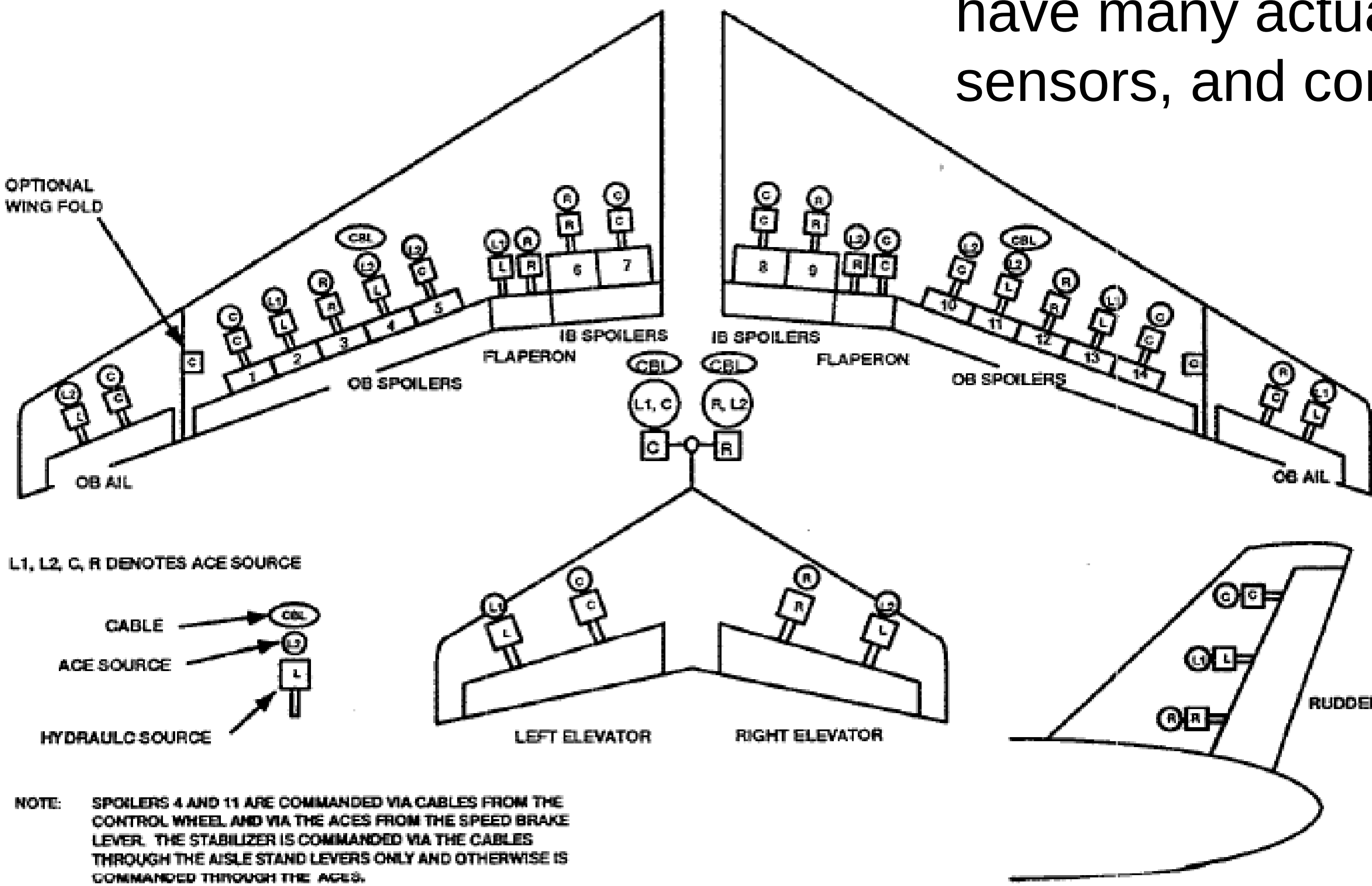




A hydraulic actuator is used to move the elevator surface

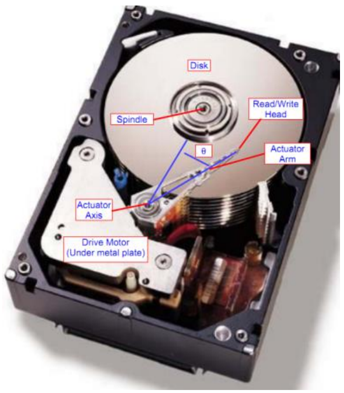
Distribution of 777 Primary Actuators [Yeh, 96]

“Real” systems can have many actuators, sensors, and computers



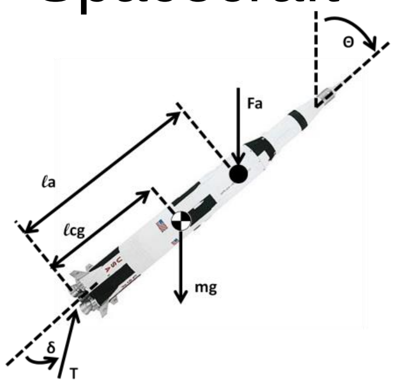
Many Other Applications of Control Systems….

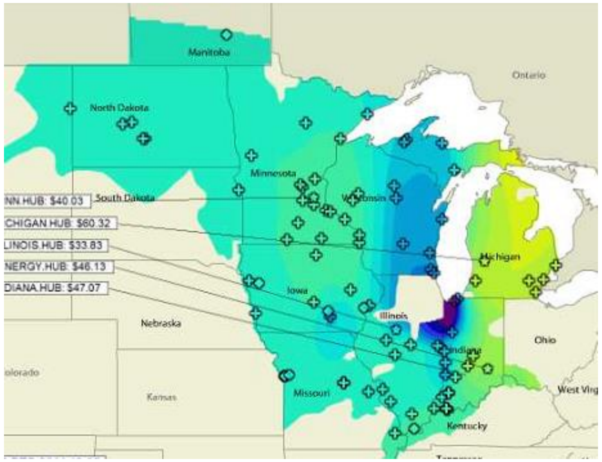
Disk Drives



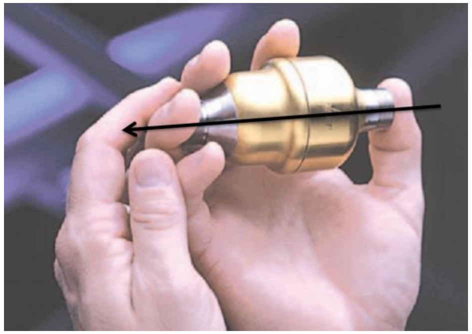
Wind Turbines (Power Electronics)

Spacecraft





Power Grid



Biomedical Devices

Summary

- Feedback: Compare **measurement** with a **desired value** and use the difference to determine control **action**
- Why Feedback?
  - Feedback is not needed if the plant model is exact
  - Reasons our knowledge is not exact:
    - unknown external disturbances
    - inaccuracies in our model of the plant behavior
- Issues:
  - Performance trade-offs
  - Need to consider measurement errors (noise, bias, etc)
  - Poorly designed controllers may cause instability