Sensing, Actuation, Control

ENES 100

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(with enormous thanks to Prof. Bill Levine)

OUTLINE:

- Some example control systems
- Feedback: Open loop vs. closed loop (PID control)
- Simple hovercraft circuits
- Hovercraft control issues
The Toilet

- 2000 year old control system
- System not used for present purpose until 19th century (cholera epidemics)

- Sensor: float
- Actuator: valve
- Power: water level
- Failsafe: overflow tube
The Toilet

- 2000 year old control system
- System not used for present purpose until 19th century (cholera epidemics)
Power Brakes (e.g. disk)

- Manual activation
- Separate hydraulic networks (per brake or per opposite pair)
- Additional failsafe (optional): power needed to hold brake open (fails closed)

- Sensor: foot pedal
- Actuator: brake calipers
- Power: hydraulic
- Failsafe: dual system
Power Brakes (e.g. disk)

- Manual activation
- Separate hydraulic networks (per brake or per opposite pair)
- Additional failsafe (optional): power needed to hold brake open (fails closed)

- Sensor: foot pedal
- Actuator: brake calipers
- Power: hydraulic
- Failsafe: dual system
Antilock Brakes

- Each wheel monitored separately for significant deviation in wheel speed
- Each wheel controlled/pulsed separately
- Problem: contaminated sensors
- Add’l sensors: wheel angle & gyroscope

- Sensor: wheel speed
- Actuator: pulse emitter
- Power: hydraulic
- Failsafe: manual, sensors
Antilock Brakes

- Each wheel monitored separately for significant deviation in wheel speed
- Each wheel controlled/pulsed separately
- Problem: contaminated sensors
- Add’l sensors: wheel angle & gyroscope
Fletched Arrow

- Bare shaft: completely unstable
- Weighted tip: slightly more stable
- Fletching acts as control mechanism (correction proportional to deviation)

- Sensor: fletching
- Actuator: fletching
- Power: pressure
- Failsafe: n/a
Fletched Arrow

- Bare shaft: completely unstable
- Weighted tip: slightly more stable
- Fletching acts as control mechanism (correction proportional to deviation)

- Sensor: fletching
- Actuator: fletching
- Power: pressure
- Failsafe: n/a
Steam Valve

- Plug/spring acts as control mechanism (correction proportional to deviation: higher pressure => valve opens more)

- Sensor: spring-loaded piston
- Actuator: valve
- Power: (steam) pressure
- Failsafe: backup/none
Steam Valve

- Sensor: spring-loaded piston
- Actuator: valve
- Power: (steam) pressure
- Failsafe: backup/none

- Plug/spring acts as control mechanism (correction proportional to deviation: higher pressure => valve opens more)
Centrifugal Governor

- Sensor: centrifugal pendulum
- Actuator: valve
- Power: torque on shaft
- Failsafe: backup/none
Centrifugal Governor

- Also called the “flyball” governor
- Proportional control: the faster the rotation, the more the valve closes
- On nearly every steam engine made

- Sensor: centrifugal pendulum
- Actuator: valve
- Power: torque on shaft
- Failsafe: backup/none
Feedback Control

**OPEN LOOP**
- Power Brakes
- Power-Assist Steering
- Manual Throttle

**CLOSED LOOP**
- Anti-Lock Brakes
- Compass-Assisted Steering
- Governor-Controlled Throttle
Power Brakes

OPEN LOOP

- Input to System
- Controller
  - Software/Hardware
- Plant
  - Thing being Controlled
- System Output

Foot on Pedal
- Magnify
  - Force
- Brake System
  - Car Slows
Anti-Lock Brakes

CLOSED LOOP

Input to System

Controller

Plant

Software/Hardware

Thing being Controlled

System Output

Feedback

Foot on Pedal

Even or Pulsed Force

Individual Brakes per Wheel

Car Slows

Feedback: Wheel rotation speed
Are any wheels slipping?
Are any wheels rotating much more slowly than the others?
If so, slipping brakes are pulsed to try to recover traction.
Power-Assist Steering

**OPEN LOOP**

- **Input to System** → **Controller** (Software/Hardware)
- **Plant** (Thing being Controlled) → **System Output**
- **Torque on Steering Wheel** → **Magnify Force** (gain is variable, rel. to veh. speed)
- **Hydraulic Steering System** → **Car Turns**
- **Vehicle Speed**
Compass-Assisted Steering

CLOSED LOOP

Feedback: Current vehicle direction of travel
If direction of vehicle is not equal to the desired compass point, control system adjusts steering appropriately (note: vehicle can point one way and go another)
Manual Throttle

**OPEN LOOP**

- **Controller**: Software/Hardware
- **Plant**: Thing being Controlled
- **Input to System**
- **System Output**
- **Set Throttle**
- **Open or Close Valve**
- **Engine Fuel Line**: Engine Speeds Up (Slows Down)
Governor-Controlled Throttle

CLOSED LOOP

Controller -> Plant

Software/Hardware

Thing being Controlled

System Output

Input to System

Feedback

Set Throttle

Open or Close Valve

Engine Fuel Line

Engine Speeds Up (Slows Down)

Feedback: Engine shaft rotation speed

If load on engine increases, the rotation slows, causing the governor to open the throttle
**Sensor & Control**

**Slide 21**

**Hovercraft A**

**Open Loop**

- **Input to System**
- **Controller** (Software/Hardware)
- **Plant** (Thing being Controlled)
- **System Output**

- **Countdown Timer**
- **Turn Right**
- **Steering Mechanism**
- **Hovercraft Turns**
Hovercraft B

CLOSED LOOP

Feedback: Orientation changes → course changes
As hovercraft changes orientation with respect to tape, light sensor readings change, causing course corrections
PID Controller

**Proportional, Integral, Derivative**

- **Proportional** term ensures the system reacts as soon as there is a change in the system: change in new output follows the error.
- **Integral** term provides hysteresis, tracks effectiveness of control system: measures delta between output and input to date.
- **Derivative** term anticipates future behavior: reacts to quick changes in plant output vs. input.

\[
u(t) = K_P e(t) + K_I \int_0^t e(t) \, dt + K_D \frac{de}{dt}
\]
Example System

Thermostat — A Popular Controls Example

- Water heater: controlled by voltage
- Sensor: temperature (V representing T)
Example System

Thermostat — A Popular Controls Example

- Response of system to step input
while (1)
    error = desired() - reading();
    increase_temp( error * pGain );
while (1)
    cum_E += [desired() - reading()];
    cum_E = bound_cumulative_error( cum_E );
    increase_temp( cum_E * iGain );
PI Controller

while (1)
    error = desired() - reading();
    cum_E += error;       // and then bound it
    increase_temp(    error * pGain +
                      cum_E * iGain );
PID Controller (predictive)

```c
error = desired() - reading();
cum_E += error; // and then bound it
delta = prev_reading - this_reading;
increase_temp( error * pGain +
              cum_E * iGain +
              delta * dGain );
```
Circuits: Relays

Two VERY DIFFERENT things:
- trip voltage (to power electromagnet)
- max current (through switch)
Circuits: Simple Fan Control

Downside: only on/off control
Circuits: Reversing Fans

* thanks to Prof. Wes Lawson
Hovercraft Control Issues

Issues you will have to address:

- Sensing location
- Sensing speed/direction
- Changing location/speed/direction
- Making informed decisions
Sensing Location

- Echolocation (distance from walls)?
- Dark/light sensor (following tape)?
- Magnetic sensor (following tape)?
- GPS (absolute coordinates)?
Sensing Speed/Direction

- Is following tape/walls sufficient?
- What about angular momentum?
Changing Orientation

Turning is obvious ... or is it?

How do you *stop* turning?

Forward thrust is obvious ... or is it?

Are your fans perfect?
**NXT vs. RCX: servos**

Does not necessarily *simplify* control …

**BUT** — reduces number of outputs by 1

**AND** gives a finer degree of control
Some Things to Think About

Which is likely to be easiest?

When you drive, do you look ahead to turn?
Some Things to Think About

How do you tell the difference?

And does it matter?
Some Things to Think About

How do you tell the difference?

And does it matter?
NXT vs. RCX: sensor inputs

4 inputs vs. 3 — RCX has 3 inputs:
NXT vs. RCX: sensor inputs

4 inputs vs. 3 — **NXT has 4:**
Bottom Line

The control problem will be your biggest headache when designing your hovercraft.

Give it a lot of thought.