Systems Engineering/Process Control L1

- What is Systems Engineering/Process Control?
- Graphical system representations
- Fundamental control principles

Reading: *Systems Engineering and Process Control:* 1.1–1.4

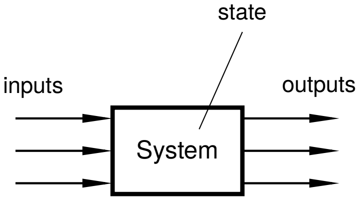
What is Systems Engineering?

Systems Engineering is about **dynamical systems**

- How can dynamical systems be modeled?
- How to understand behavior of complex interconnected systems?
- How to make a system behave as desired?

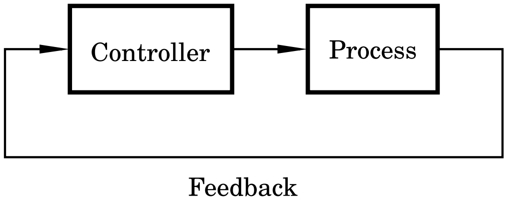
What is a dynamical system?

- **Dynamical** systems have a “memory” — an **inertia**
- Outputs does not directly depend on the inputs; there is an inertia
- Are often modeled abstractly using block diagrams:



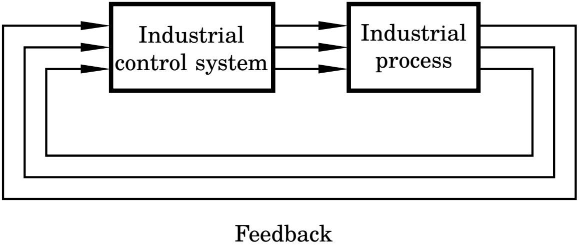
What is control?

- It is about dynamical systems with **feedback**
- Objective: control system (process) to make it behave as desired
- Schematic figure of a feedback system:



What is process control?

- Control of industrial processes to achieve desired behavior
- Typical objectives: Safety, predictability, profitability

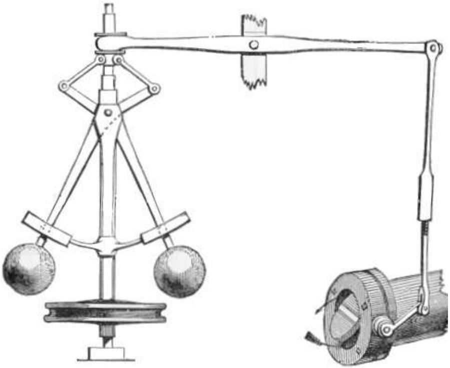


Early control example

Watts steam engine (first from 1775)

- Increased efficiency compared to previous versions
- Could operate with constant speed despite disturbances

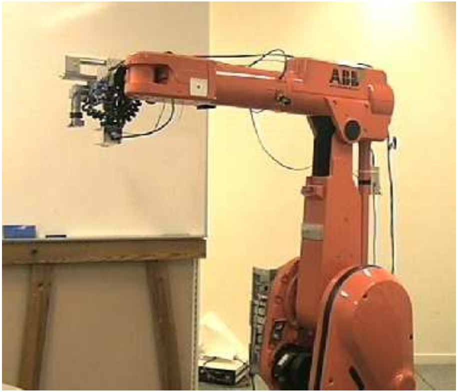
Centrifugal governor



- Measurement of rotation speed
- Corrects inflow of steam based on machine rotation speed
- System analyzed in [Maxwell, *On Governors*, 1868]
- [https://www.youtube.com/watch?v=SiYEtnlZLSs]

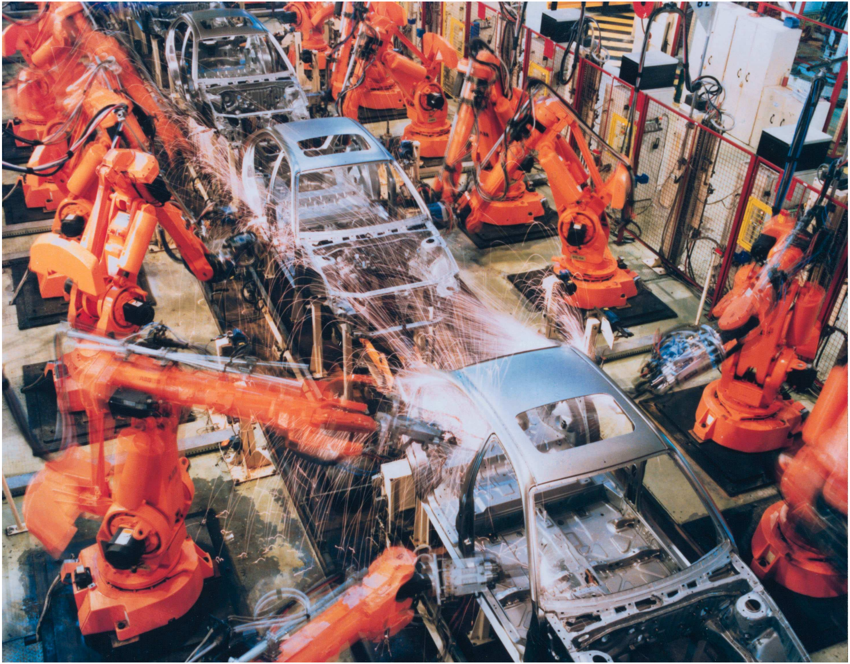
Current control example

ABB IRB 2000



- No. of axes: 6
- Max load: 10 kg
- Range: 1542 mm
- Repetition accuracy: ± 0.1mm
- Mass: 350 kg

Design compromise: Power, speed, stiffness, repeatability **vs.** cost, weight, power consumption



Stabilization

Many systems need stabilization using control to work as desired

- Airplanes
- Bicycles
- Segways
- Rockets
- Exothermic reactions
- ...

Inverted pendulum problems

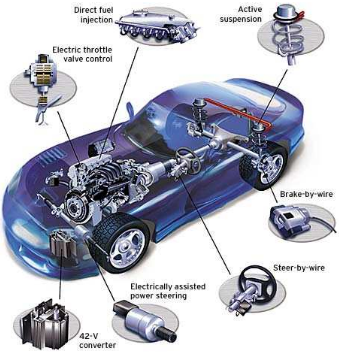
- Segway/swagway/monowheel
- Space-X space-craft landing:

  [https://www.youtube.com/watch?v=4Ca6x4QbpoM, 2009]

- Fundamental control problem: Balance an inverted pendulum

Cars

- Motor control
- Power transmission
- (Adaptive) Cruise control
- Anti-spin systems
- Lane assistance
- Parking assistance
- …



Autonomous aerial vehicles

Unmanned stealth airplanes

Quadrocopters

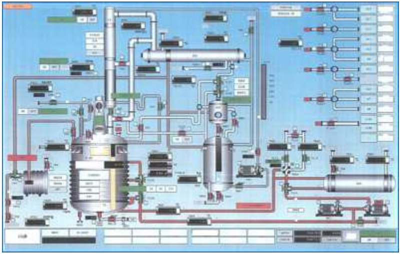
Misc. control applications

[https://vimeo.com/110346531]

[Raffaello D'Andrea, Institute for Dynamic Systems and Control, ETH, Switzerland, 2015]

Process industry

Perstorp ABs chemical production site in Stenungsund



Schematic figure of a process plant

Optimal bacteria growth

- Production of protein from bacteria
- Cells are fed with glucose
- Avoid starvation and over-feeding
- Lack of measurements makes it hard to find optimal feed-rate

[Lena de Maré, Automatic Control LTH, 2006]

Biology

Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure, and cholesterol level.

The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.

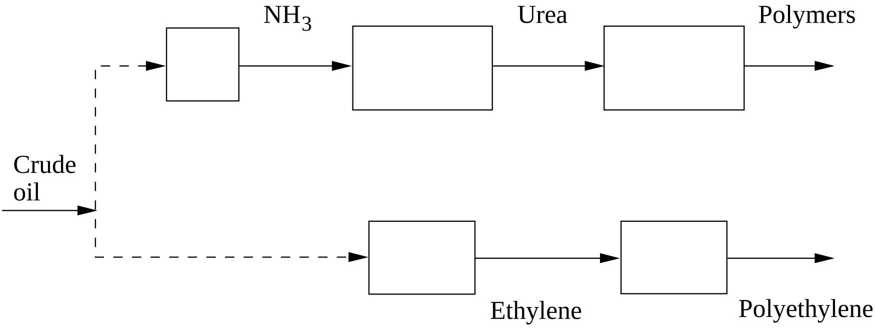
[Mahlon B. Hoagland and B. Dodson. The Way Life Works, 1995]

Graphical process representations

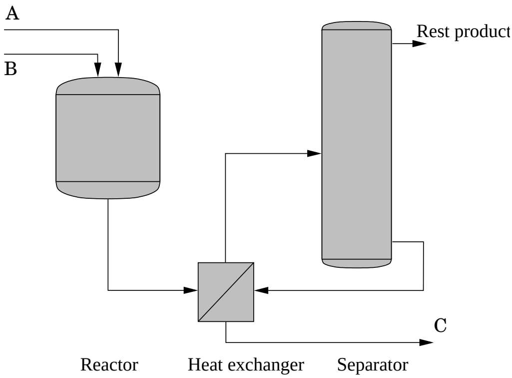
- General process layouts
- Process flow sheets
- Process and instrumentation (P/I) diagrams
- Block diagrams

General process layout

- Crude sketch of material flow for polymer/polyethylene manufacturing

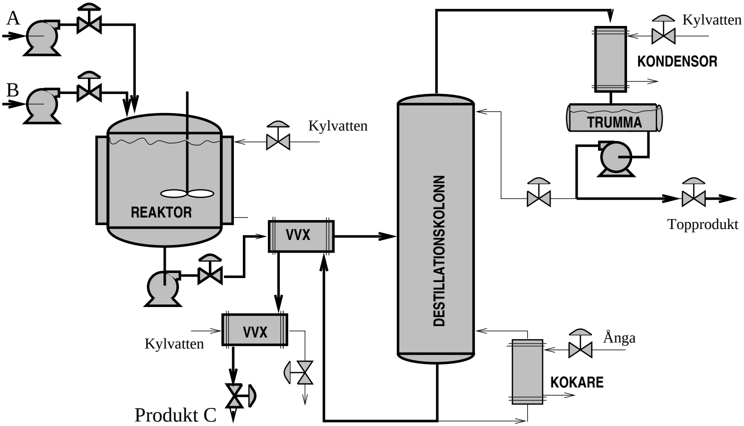


Process flow sheet



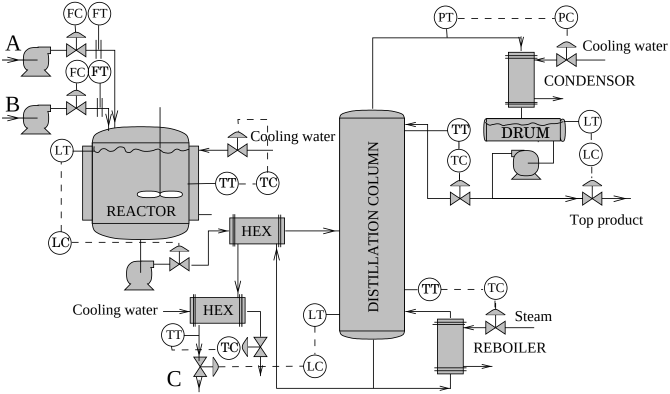
- product flows
- important unit operations
- fundamental sequence of operations

Detailed process flow sheet



- all important flows
- all units (e.g., pumps, valves)
- “all” steps (including, e.g., reboilers, condensators)

Process and instrumentation diagram (P/I-diagram)



Detailed process flow sheet with:

- instruments (sensors, controllers, actuators)
- all information flows (e.g., measurement to controller)

Instrument symbols

TIC

First letter: **Quantity**

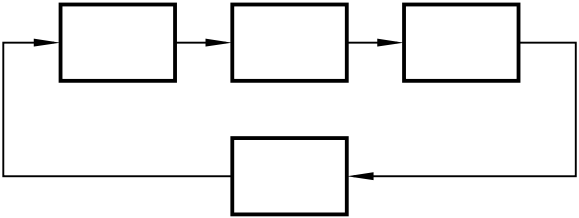
- T = temperature
- L = level
- F = flow
- P = pressure
- (C/Q = concentration)
- (X = power)

Second (and third) letter: **Function**

- T = transmitter (sensor)
- C = controller
- I = indicator
- R = recorder
- A = alarm

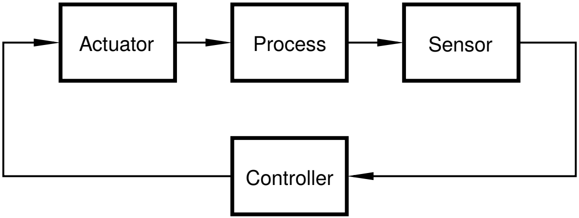
Standardized in *ISA Standard S5.1*

Block diagram



- Block diagrams reflect *information flow* between system parts
- May *not* coincide with physical flows of system
  (there may not even be any physical flows in the system)
- So the arrows transmit *information*
- Can draw different block diagrams for same system depending on:
  - desired level of detail
  - purpose of control

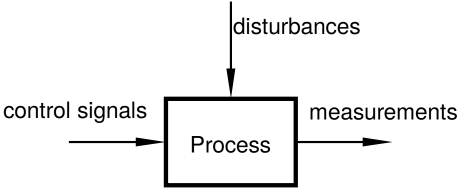
Control system parts



- Sensor/transmitter
  - Measures what happens in the system
- Controller
  - Decides how the system is controlled
- Actuator
  - Can influence the system

Often sensors and actuators are not drawn, but are included in the process

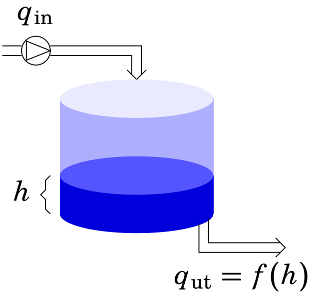
Block diagram for one process



- *Control signals*: Affect process and can be freely manipulated. (often called *inputs* or *manipulated variables*)
- *Disturbances*: Affect process but cannot be manipulated.
- *Measurements*: Contain information about system quantities (often called *outputs* or *measurement signals*)

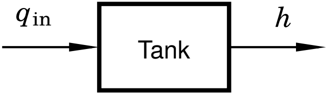
Example: Tank process

Reality:



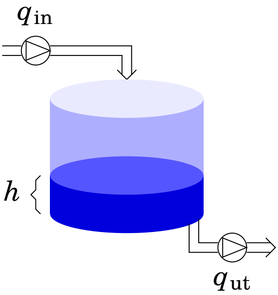
- We control the inflow q_{in}
- We measure the height h

Block diagram:



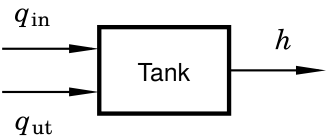
Example: Tank process

Reality:



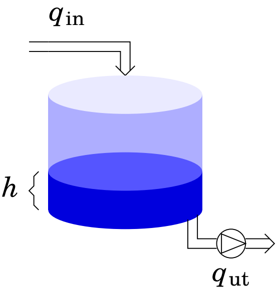
- We control:
  - the inflow q_{in}
  - the outflow q_{ut}
- We measure the height h

Block diagram:



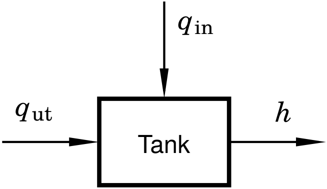
Example: Tank process

Reality:



- We control the outflow q_{ut}
- We measure the height h
- The inflow q_{in} is a disturbance (that we cannot manipulate)

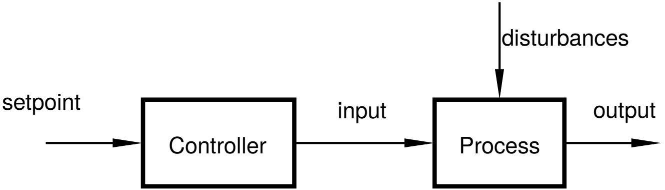
Block diagram:



Fundamental control principles

- Open-loop control / feedforward
- Closed-loop control / feedback

Open-loop control



- The controller tries to steer the output to the setpoint (reference)
- Does not get information from the process (feedback)
- Only information (feedforward) from the setpoint
- Open-loop system

Pros and cons with open-loop control

Pros:

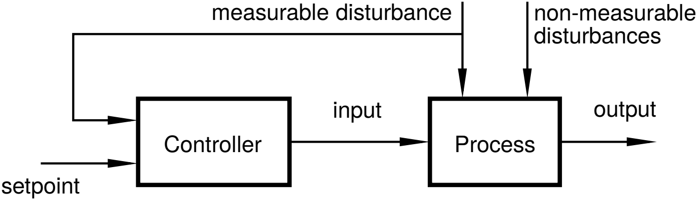
- Simple
- Does not require any sensors

Cons:

- Works only for stable processes
- Good performance requires very accurate model of the system
- Cannot compensate for unknown disturbances and model errors

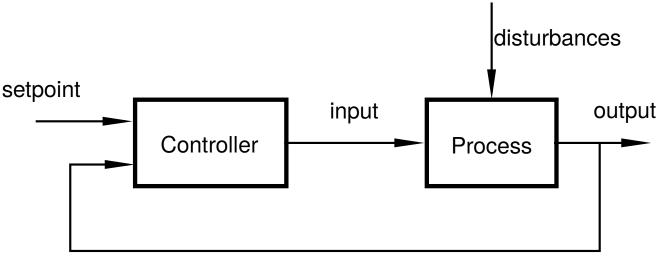
Open-loop control with feedforward

If a disturbance is measurable, we can feedforward from it:



- Requires sensors (to measure disturbance)
- Requires model of how the disturbance affects the process
- Cannot compensate for other disturbances and model errors

Closed-loop control



- Feedback from output
- Controller steers output towards setpoint
- Closed-loop system

Pros and cons with closed loop control

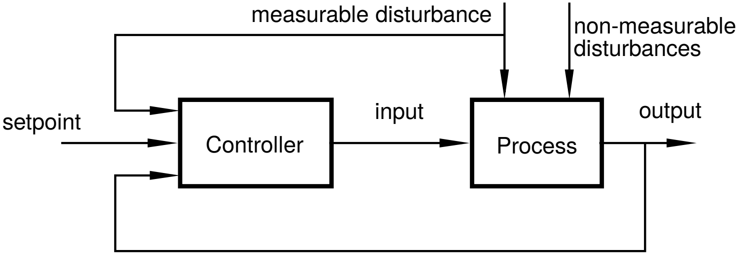
Pros:

- Can reduce disturbance sensitivity, increase speed, improve accuracy
- Can stabilize an unstable system
- It is often enough with a crude model of the system
- Can make new products and solutions possible!

Cons:

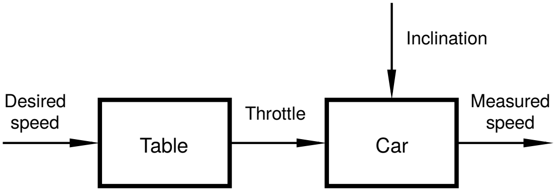
- Requires sensors (for the feedback)
- Can cause oscillatory behavior and instability
- Measurement disturbances are fed back to the process

Closed-loop control with feedforward



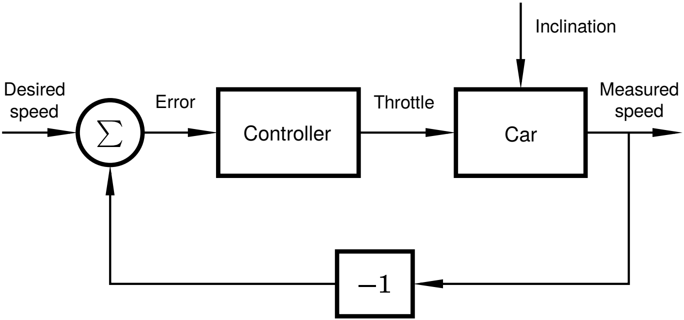
- Measurable disturbances can be compensated using feedforward
- Other disturbances and model errors compensated using feedback

Example: Cruise control with feedforward



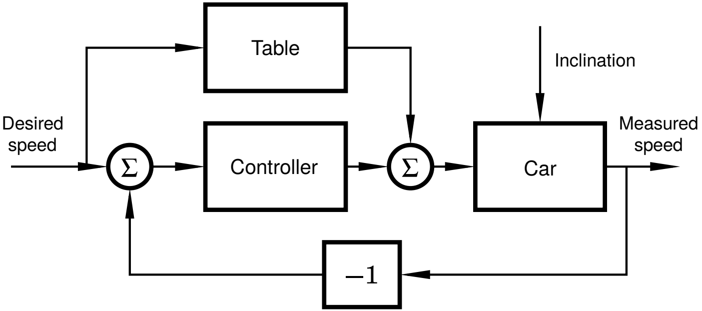
- Open-loop control
- Problems?

Example: Cruise control with feedback



- Closed-loop control
- Controller:
  - Error > 0: increase throttle
  - Error < 0: decrease throttle
  - (But how much?)

Example: Cruise control with feedback and feedforward



- Both proactive and reactive
- Could also feedforward from:
  - inclination (GPS)
  - distance to car in front (radar/camera)

Summary

[https://www.youtube.com/watch?v=XJLMW6l303g]