IVR: Introduction to Control

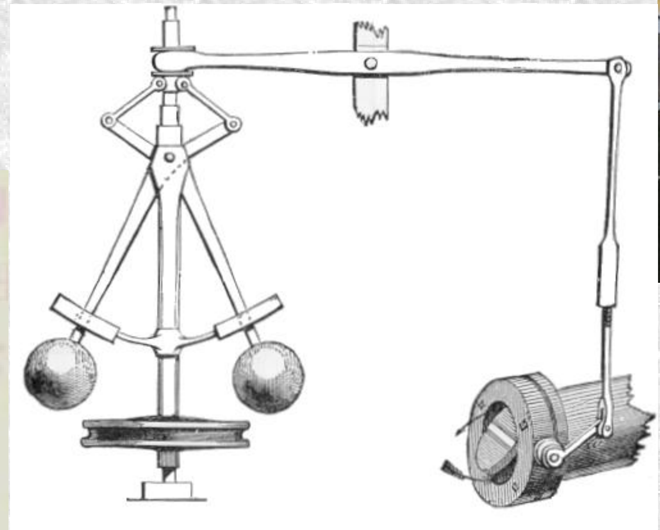
OVERVIEW

- Control systems
- Transformations
- Simple control algorithms

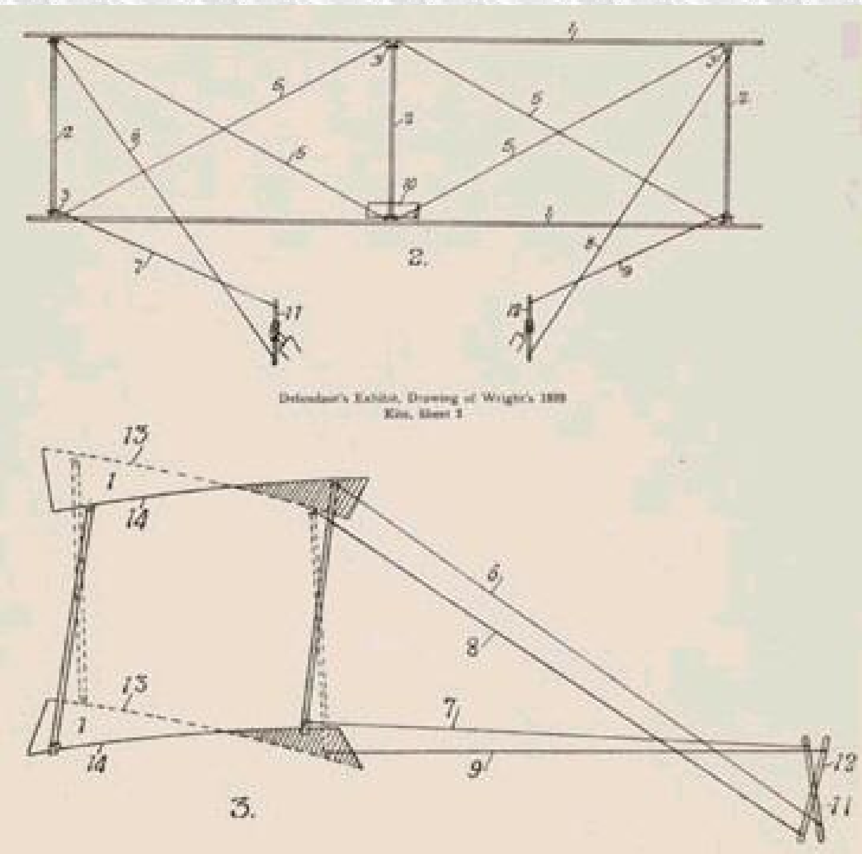
History of control

Centrifugal governor

- M. Boulton and J. Watt (1788)
- J. C. Maxwell (1868) *On Governors.*



Science Museum London
(Dr. Mirko Junge)



Pilot control of fixed-wing air-craft: Wright Brothers (1899) (rather than “inherent stability”)

flight = wings + engines + **control**

Examples of Control

- Aeroplane control
- Cruise control
- Robot control
- Electronics
- Power control
- Thermostat
- Fire control
- Process control
- Space craft control
- Homeostasis & biological motor control
- Control in economy
- ...

Unimate 500 Puma (1983)
Deutsches Museum, Munich
(Theoprakt)

Policeman on Segway PT in Vilnius (Kulmalukko)

Proton Rocket (NASA)

The control problem

How to make a physical system (such as a robot) function in a specified manner?

Particularly when:

- The function would not happen naturally
- The system is subject to a large class of perturbations or changes, e.g.
  - get the mobile robot to a goal
  - keep a walking robot upright
  - move the end-effector to a given position
  - move a camera to track an object

Control	Example
Dynamical system (“plant”)	A room (containing air)
Continuous states	Temperature at certain points in the room
Physical input and output (to/from the system)	Heater and measurement device
Control actuators	A way of switching the heater on or off
Controller	Thermostat

Control

- Dynamical system
- States
- Input and output
- Control actuators
- Controller

Example

- Robot in an environment
- Position and velocity of the robot's DoF
- Sensors and body/ effectors
- Motors, muscles, ...
- Controller hardware/ Control algorithm

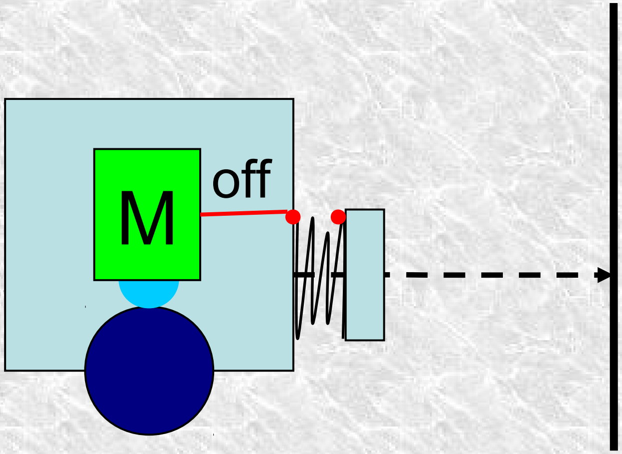
Control	Example
Dynamical system	Khepera robot near a wall
States	Distance to the wall
Input and output	IR sensors and wheel speeds
Control actuators	Motors including low-level control
Controller	???

Questions & Problems

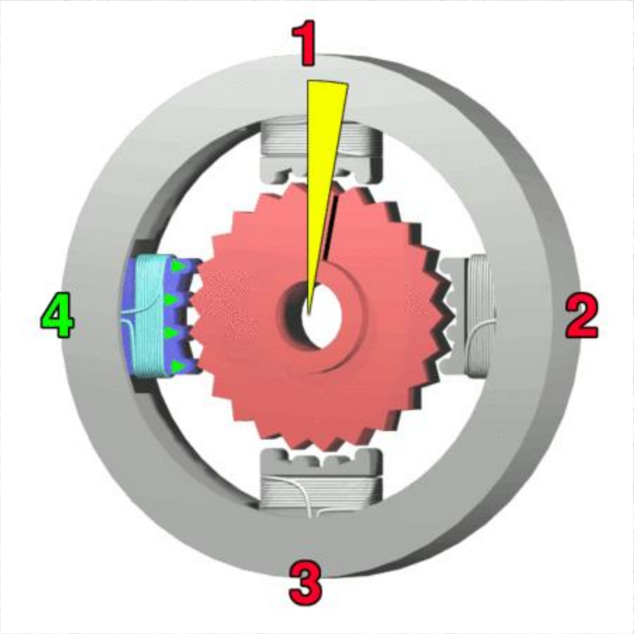
- What control strategy?
- Stability
  - Does the system continue to behave as desired?
- Controllability and observability
  - Are the critical variables accessible and measurable
- Delays
  - Is the measurement up to date, when does the control take effect?
- Efficiency
  - Can the same effect be achieved with less effort?
- Adaptivity
  - Is the control strategy appropriate for changing conditions?

“Bang-bang” control

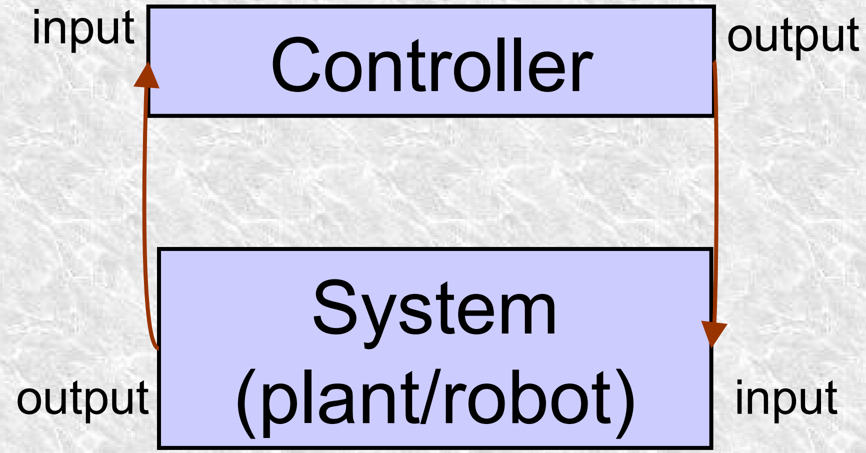
- Simple control method is to have physical end-stop …



- Stepper motor is similar in principle:



Controller



- ‘A device which monitors and affects the operational conditions of a given dynamical system’
- The controller receives the outputs of the controlled system and adjusts the input variables of this system.
- It may also receive signals from a (human) operator or from another controller
- Controllers often aims at affecting the system outputs to stay close to a desired set-point (homeostasis)
- The difference of system output and set-point can serve as feedback telling the controller to what extent the control goal was achieved

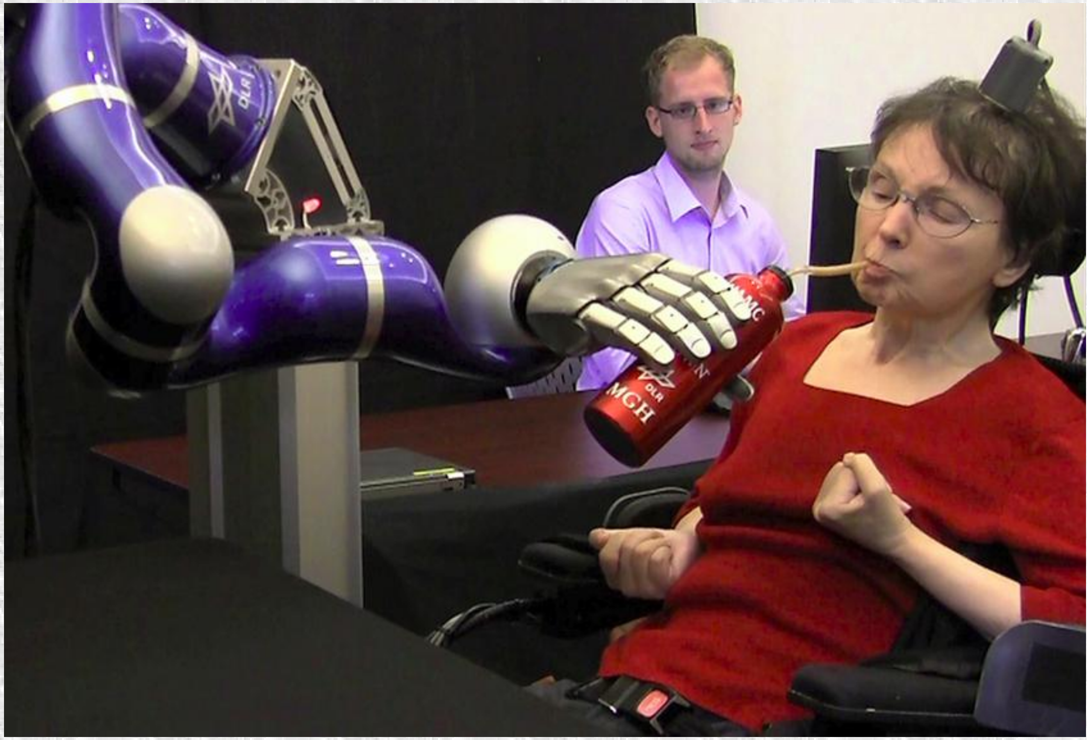
Approaches to the control problem

- For a desired outcome, what are the motor commands? ⇨ *Inverse model*
- For given motor commands, what is the outcome? ⇨ *Forward model*
- From observing the outcome, how should we adjust the motor commands to achieve a goal?

⇨ *Feedback control*

Levels of control problem

KUKA
robotic arm



Brown University

- Want to move robot hand through set of positions in task space: $X(t)$
- $X(t)$ depends on the joint angles in the arm $A(t)$
- $A(t)$ depends on the coupling forces $C(t)$
- delivered by transmission from motor torques $T(t)$
- $T(t)$ produced by the input voltages $V(t)$

The control system

$$\longrightarrow \; V(t) \longleftrightarrow T(t) \longleftrightarrow C(t) \longleftrightarrow A(t) \longleftrightarrow X(t) \; \longrightarrow$$

command	voltage	torque	force	angle	position	camera

Depends on:

- Kinematics and geometry: Mathematical description of the relationship between motions of motors and end effector as transformation of coordinates
- Dynamics: Actual motion also depends on forces, such as inertia, friction, etc…

Forward models

V(t) ⟷ T(t) ⟷ C(t) ⟷ A(t) ⟷ X(t)

→

- Forward kinematics is not trivial but usually possible
- Forward dynamics is hard and at best will be approximate
- But what we actually need is *backwards* kinematics and dynamics

Difficult!

←

Inverse models

V(t) ⟷ T(t) ⟷ C(t) ⟷ A(t) ⟷ X(t)

- **Find motor command given desired outcome** (find V given X)
- Solution might not exist
- Ill-posed problems in redundant systems
- Non-linearity of the forward transform
- Robustness, stability, efficiency, ...
- Partial solution and their composition

Summary

- In order to execute a task, robots need information about
  - what actions to perform
  - how to execute the actions
  - the effects on their environment
- This information may be maintained explicitly, (e.g. by a model) or incrementally (in feedback control) or in a combination of both.
- In order to obtain quantitative description of the involved processes, we'll need a systematic approach: Control theory