IVR: Open- and Closed-Loop Control

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informatics

Overview

- Open-loop control
- Feed-forward control
- Towards feedback control

Controlling the motor over time

Process model

$$V_B = k_1 s + \frac{M}{k_2} R \frac{ds}{dt}$$

Stationary behaviour (steady state)

$$s\,(t \to \infty) = \frac{V_B}{k_1}$$

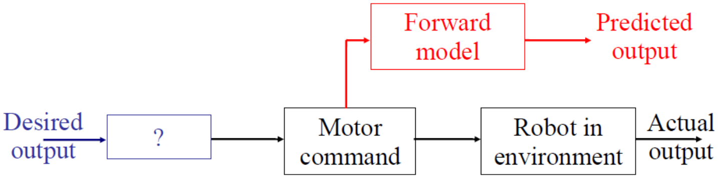
Inverse model:

$$V_B = k_1\, s_{\text{goal}}$$

Solution provides forward model:

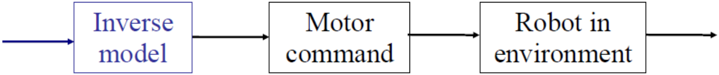
$$s\,(t) = s_0 \mathrm{e}^{-\frac{MR}{k_1 k_2}(t - t_0)} + \frac{V_B}{k_1}\left(1 - \mathrm{e}^{-\frac{MR}{k_1 k_2}(t - t_0)}\right)$$

The control problem



- Forward: Given the control signals, can we predict the motion of the robot?
- Inverse: Given the desired motion of the robot: Can we determine the right control signals?
- Control theory aims at unique or easy exact solutions
- Difficult in the presence of non-linearities or noise

Open loop control



Examples:

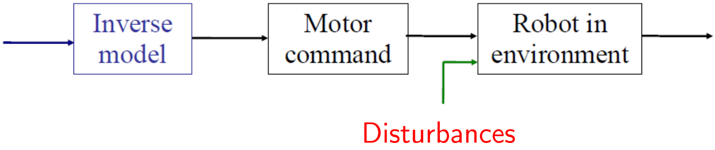
- To execute a memorised trajectory, produce appropriate sequence of motor torques
- To obtain a goal, make a plan and execute it
  - means-ends reasoning could be seen as inverting a forward model of cause-effect
- 'Ballistic' movements such as saccades

Open loop control

- Potentially cheap and simple to implement e.g. if solution is already known.
- Fast, e.g. useful if feedback would come too late.
- Benefits from calibration e.g. tune parameters of approximate model.
- If model unknown, may be able to use statistical learning methods to find a good fit e.g. using neural networks

Open loop control

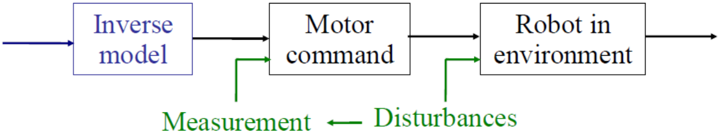
Neglects possibility of disturbances, which might affect the outcome.



For example:

- Change in temperature may change the friction in all the robot joints.
- Unexpected obstacle may interrupt trajectory

Feed-forward control



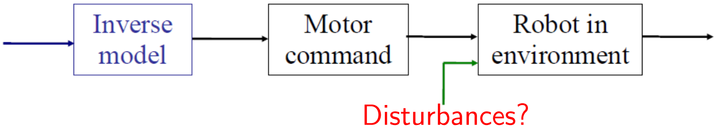
- One solution is to measure the (potential) disturbance and use this to adjust the control signals.
- For example
  - Thermometer signal alters friction parameter.
  - Obstacle detection produces alternative trajectory.

Feed-forward control

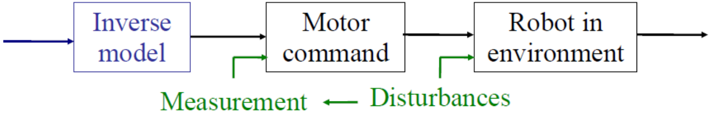
- Can sometimes be effective and efficient.
- Requires anticipation, not just of the robot process characteristics, but of possible changes in the world.
- Does not provide or use knowledge of actual output (for this need to use **feedback** control).

Control paradigms

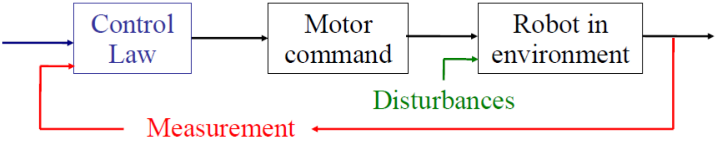
Open loop control



Feed-forward control



Feedback control

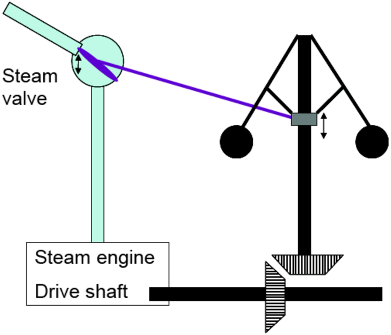


Combining control methods

- In practise most robot systems require a combination of control methods
  - Robot arm using servos on each joint to obtain angles required by geometric inverse model
  - Forward model predicts feedback, so can use in fast control loop to avoid problems of delay
  - Feed-forward: Measurements of disturbances can be used to adjust feedback control parameters
  - Training of an open-loop system is essentially a feedback process

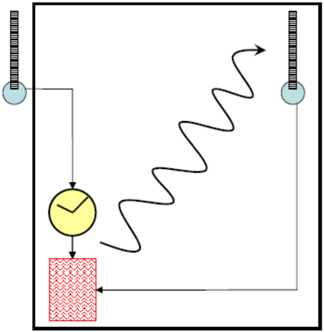
Feedback control

Example: Watt governor

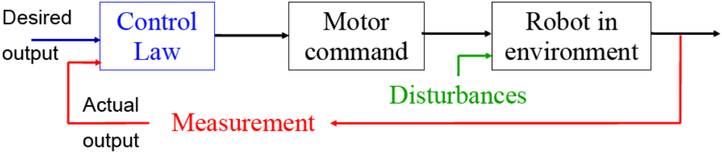


Compare: Room heating

Open loop: For desired temperature, switch heater on, and after pre-set time, switch off.
Feed forward: Use thermometer outside room to compensate timer for external temperature.
Feedback: Use thermometer inside room to switch off when desired temperature reached.
NO PREDICTION REQUIRED!



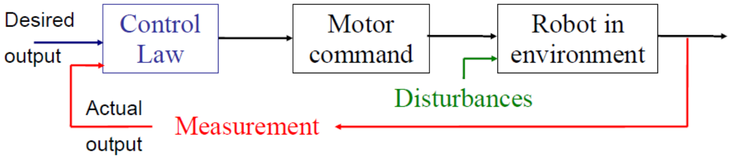
Control laws in feed-back control



On-off: Switch system if desired = actual

Servo: control signal proportional to difference between desired and actual, e.g. spring:

Complex control law



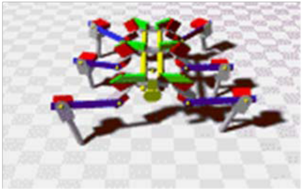
- May involve multiple inputs and outputs
- E.g. 'homeostatic' control of human body temperature
  - Multiple temperature sensors linked to hypothalamus in brain
  - Depending on difference from desired temperature, regulates sweating, vasodilation, piloerection, shivering, metabolic rate, behaviour. . .
  - Result is reliable core temperature control

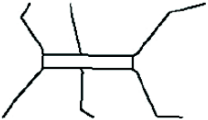
Negative vs. Positive Feedback

- Examples so far have been negative feedback: control law involves subtracting the measured output, acting to decrease difference.
- Positive feedback results in amplification:
  - e.g. microphone picking up its own output
  - e.g. ‘runaway’ selection in evolution
- Generally taken to be undesirable in robot control, but sometimes can be effective
  - e.g. in exploratory control, self-excitation
  - model of stick insect walking (H. Cruse et al., 1995)
  - to counteract negative feedback from the environment

Stick insect walking

- 6-legged robot has 18 degrees of mobility.
- Difficult to derive co-ordinated control laws
- But have linked system: movement of one joint causes appropriate change to all other joints.
- Can use signal in a feed-forward loop to control 12 joints (remaining 6 use feedback to resist gravity).





Advantages of feedback control

- Major advantage is that (at least in theory) feedback control does not require a model of the process.
  - E.g. thermostats work without any knowledge of the dynamics of room heating (except for time scales and gains)
- Thus controller can be very simple and direct
  - E.g. hardware governor does not even need to do explicit measurement, representation and comparison
- Can (potentially) produce robust output in the face of unknown and unpredictable disturbances
  - E.g. homeostatic body temperature control keeps working in unnatural environments

Issues to be solved

- Requires sensors capable of measuring output
  - Not required by open-loop or feed-forward
- Low gain is slow, high gain is unstable
- Delays in feedback loop will produce oscillations (or worse)
- In practise, need to understand process to obtain good control:
  - E.g. James Clerk Maxwell's analysis of dynamics of the Watt governor