Introduction to Control

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thanks to Karl-Erik Årzen, Karl Johan Åström, Erik Johannesson
Reglerådertechnik, läran om styrda system, ett grundläggande ämne inom ingenjörsvetenskapen.
The Idea of Feedback

Compare the actual result with desired result
Take actions based on the difference

This seemingly simple idea is tremendously powerful in many different context: science, engineering, management...

Use of feedback has often been revolutionary

Feedback is also called closed loop control. The opposite is feedforward or open loop control: make a plan and execute it
**Example: Cruise Control**

Typical regulation problem – keep velocity constant

- Process input or control variable: gas pedal (throttle) $u$
- Process output: car speed $v$
- Desired output or reference signal: desired car speed $r$
- Main disturbance: slope $\Theta$
Cruise Control: Open loop

- Open loop
- Problems?
Cruise Control: Feedback

- Closed loop
- Simple controller:
  - Error > 0: increase throttle
  - Error < 0: decrease throttle

Will this simple controller work?
Feedback (återkoppling)

Feedback has some amazing properties, it can
+ make good systems out of bad components
+ reduce impact of disturbances and sensitivity to component variations
+ create desired behavior, for example linear behavior from nonlinear components or stable system from unstable

The major drawbacks are that
- Feedback can cause instabilities
- Sensor noise is fed into the system
Open loop, feedforward (öppen loop, framkoppling)

+ Reduces impact of measurable disturbances
+ Allows fast reference changes (look-ahead)
- Good process models needed
- Stable system needed
The ABB IRB 2000 Robot

- Axes: 6
- Payload: 10 kg
- H-Reach: 1542 mm
- Repeatability: ±0.1 mm
- Robot Mass: 350 kg

Design compromise:
Power (speed, force), stiffness (repeatability) **versus** cost, weight, power consumption
Robot Power and Speed

Superior control is vital for market leadership
Ball and Beam Process (Lecture 14)
Good Systems from Bad Components

Example: The **feedback amplifier**

- Invented by H. Black at Bell labs in 1927
- Rapid increase in telephone communication in 1920s
- Carrier technology (many simultaneous connections on one line) is made possible in 1917 by innovative filters
A Story: 1930s Phone Network Battle

– Long distance: need many amplifiers
– 1915 Transcontinental phone line built with 3 amplifiers
– 1921 Upgraded to 3-channel system with 12 amplifiers
– Tube amplifiers are nonlinear and distorts sound
– 1923 Bell company built 2nd line (4 channels and 20 amplifiers)
– Bell policy: technology leadership to keep monopoly. Invention of a working repeater was top priority
Idea by H. Black (1898-1983)

• Started to work on the problem 1923
• In August 1927 he got this idea:

\[
A_{fb} = \frac{V_{out}}{V_{in}} = \frac{A_{OL}}{1 + \beta \cdot A_{OL}}
\]

If \( \beta \cdot A_{OL} \gg 1 \) then \( A_{fb} \approx 1/\beta \)

• Patent filed in 1928 (with 126 claims)
• Finally awarded patent 9 years (!) later, believed ”too good to be true”.

\[\beta\cdot A_{OL} \gg 1\]
1934 Amazing Linearity Results achieved at Bell

Feedback can eliminate variations of the electronic tube
Results were spectacular

Distorted sound

Clear sound, also with many amplifiers in series

Figure 3.3  Gain frequency characteristics with and without feedback
Reproduced (with partial redrawing) by permission of H.S. Black, from
Bell System Technical Journal, 1934, 13, p. 12
The Stability Problem

- Stability problems ("singing")
- When can one use loop gains larger than 1?
- Fundamental results understanding stability by H. Nyquist and H. Bode (also Bell labs) etc in 1930-40s
Stabilize and Shape Behavior

Many systems use feedback stabilization to operate

- Airplanes
- Bicycles
- Segway
- Missiles
- Exotherm reactors
- Nuclear reactors
- ...
Shaping Behavior

Lecture by Wilbur Wright 1901:

*We know how to construct airplanes*
*We also know how to build engines*
*Inability to balance and steer still confronts students of the flying problem*
*When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance*

The main stream idea at the time was to build stable airplanes. The Wright Brothers built an **unstable** airplane that was **manoeuvrable**.
Substantial advantages are obtained by designing an unstable aircraft and using a control system to stabilize the system.
General Theory: Inverted Pendulums

Same underlying mathematics and control theory

From Rolf Johansson and Måns Magnusson, LU
The Segway Example

How should the controlled system behave?
”Keep balance and move by leaning”
Segway Variants
Control is Everywhere – But Often a Hidden Technology

• Used everywhere and very successful
• Mission-critical for many products and systems
• Not very much attention
  – Except when failing

• Why?
  – Easier to market physical things than principles, methods and ideas
What process is (was) this?

Dont try this at home!
Figure 2. Chernobyl nuclear power plant shortly after the accident on 26 April 1986.
On 2 February 1989, the first prototype JAS 39-1 crashed on its sixth flight, when attempting to land in Linköping. The accident was filmed in a now famous recording by a crew from Sveriges Television's Aktuellt. The pilot, Lars Rådeström, remained in the tumbling aircraft, and escaped with a fractured elbow and some minor injuries. The crash was the result of pilot-induced oscillation (PIO).
Power Generation and Distribution
Process Control
Buildings

- Design & Energy Analysis
- Windows & Lighting
- Natural Ventilation
- Indoor Environment
- Elevators
- Safety
- HVAC
- Vibration damping
- Sensors, Networks, Communications, Controls

Slide from UTRC
Vehicles
Automotive

Strong technology driver
Engine control
Power trains
Cruise control
Adaptive cruise control
Traction control
Lane guidance assistance
Traffic flow control
Example: Stabilization of Vehicle Dynamics

Brad Schofield Automatic Control LTH 2006
Unmanned Aerial Vehicles

The QuadRotor
Consumer Electronics
Track following in DVD players

Bo Lincoln, Automatic Control LTH 2000
Big and Small Toys

http://video.google.se/videoplay?docid=1210345008392050115&ei=tznoSrXwKqDQ2wLP1I2PDw&q=humanoid+robot&hl=sv

http://www.youtube.com/watch?v=W1czBcnX1Ww
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 Times Books 1995
Optimal Growth of Bacteria

Lena de Mare, Automatic Control LTH 2006
The Diabetese Advisor Project

From www.diadvisor.eu
Other Sciences

- Economy
  - “Controller”
  - Stocks and options
- Politics
  - Democracy = feedback
- Organization theory
  - Educational system
- …
- …
Why Work With Control?

• Can work in many different areas – no need to commit to specific field. Courses for F, E, D, C, M, I, Pi, K, B, W, N

• Fun mixture between theory and practice

• Holistic view of systems, get the complete picture, not only different small parts (future is in complex systems)

• Working with many different sort of people

So Follow Master Yoda’s Advice:
References

The presentation in large parts originates from similar material collected by KarlErik Årzen, KarlJohan Åström, Anders Robertsson, Lund University. Thanks!
The Robotics images are taken from ABB home page and video clips are from Youtube
The description of Postural dynamics originates from Rolf Johansson and Måns Magnusson Lund University
The DiAdvisor description is taken from the EU FP7 project page http://www.diadvisor.eu
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