Classical Control

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http://www.cs.aaue.dk/contribution/courses/fall2009/DE5/CC/Course.html

Objective

- To enable students to apply basic classical control techniques for analysis and design of control systems

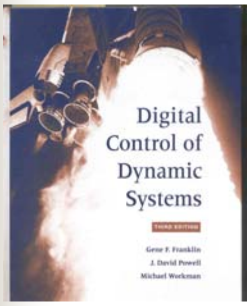
http://www.esn.aau.dk/fileadmin/esn/Studieordning/BSc_DE_jan09.pdf

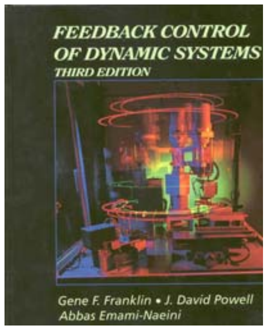
Content (2 ECTS)

- Basic concepts and principles
  - Characteristics of feedback control
  - Block diagrams
  - Transfer function models
- Frequency domain analysis
  - Bode plots, Nyquist plots
  - Poles and zeros, bandwidth, gain and phase margins
  - Stability, transient and steady-state performance
- PID control
  - Characteristics of PID control
  - PID control tuning
  - Anti-windup techniques
- Frequency response design
  - Gain controller
  - Dynamic compensators
- Root locus analysis and design

Textbooks

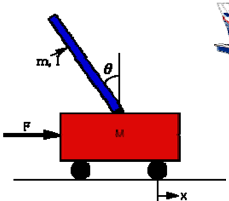
(also for Modern Control course in DE6)

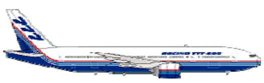




Control Tutorials for Matlab

- http://www.engin.umich.edu/group/ctm/home.text.html





MM1 Introduction to Control Engineering

Readings:

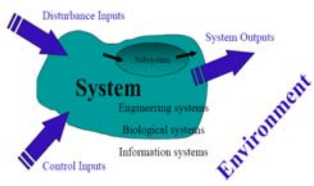
Chapter 1; Section 3.2.1 (block diagram)

After this lecture, you are expected to know

- Some basic concepts in control engineering
  - System, inputs and outputs
  - Open-loop control vs closed-loop control
  - (automatic) feedback control
  - Transfer function description
- Block diagram decription
- How to start system construction in Matlab/simuink

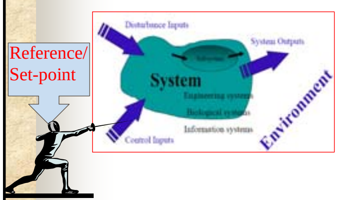
Basic Concept (I): **System and its Variables**

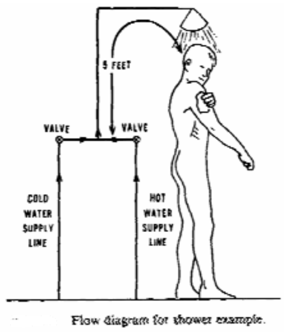
- A **system** is a collection of components which are coordinated together to perform a function
- Systems interact with their **environment**. The interaction is defined in terms of **variables**
  - System inputs
  - System outputs
  - Environmental disturbances
- **Dynamic system** is a system ehose performance could change according to time



Basic Concept (II): **Control**

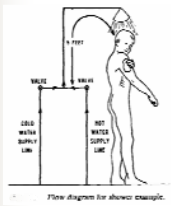
- **Control** is a process of causing a system (output) variable to conform to some desired status/value





Basic Concept (III): **Manual Control**

- **Manual Control** is a process where the **control** is handled by human being(s).
- Simple and easy…

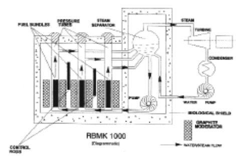


Manual Control: **Safety issue (I)**

- **Manual Control** requires the operator to have sufficient knowledge and experience in operating the considered system, oterhwise, …

Manual Control: **Safety issue (II)**

The Chernobyl Accident



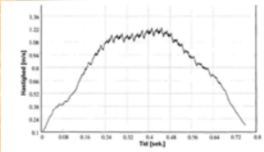
On 26 April 1986

The result of a flawed reactor design that was operated with inadequately trained personnel and without proper regard for **safety**

31 people were killed, and there have since been around 10 deaths from thyroid cancer due to the accident

Source: http://www.uic.com.au/nip22.htm

Manual Control: **Slow Response**

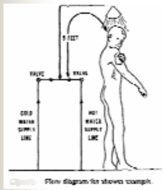


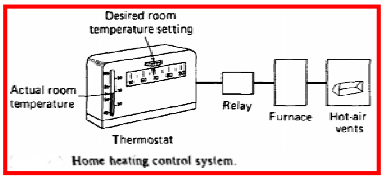
Figur 4: Viser gammel motors hastighedsprofil ved vandret placering

Basic Concept (IV): **Automatic Control**

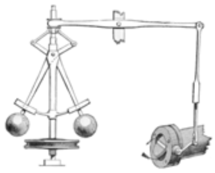
- **Automatic Control** is a control process which involves machines only

(**Control** is a process of causing a system variable to conform to some desired status/value)





Automatic Control: **Cruise Control** (Speed control)



http://en.wikipedia.org/wiki/Cruise_control

Boulton & Watt engine of 1788

Automatic Control: **BO9000 Sledge Control**

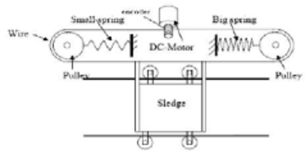
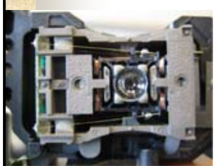
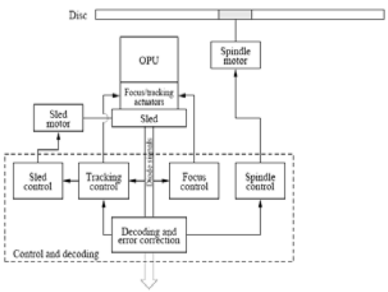


Fig. 3. Schematic diagram of BeoSound 9000 sledge system

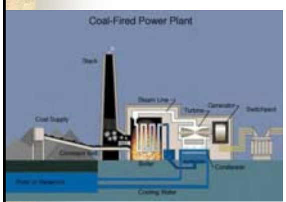
Automatic Control: **OPU Position Control**

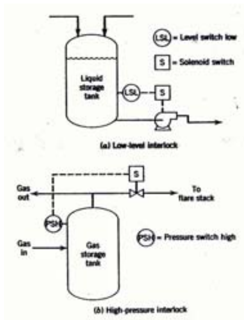




'igure 2.6: A simplified representation of the control and decoding blocks of a CD drive stsyem.

Automatic Control: **Process Control**



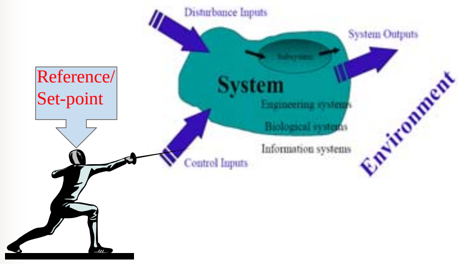


Control Classification

- **Control** is a process of causing a system variable to conform to some desired status/value
- **Open-loop Control:** A control process which does not utilize the feedback mechanism, i.e., the output(s) has no effect upon the control input(s)
- **Closed-loop Control:** A control process which utilizes the feedback mechanism, i.e., the output(s) does have effect upon the control input(s)

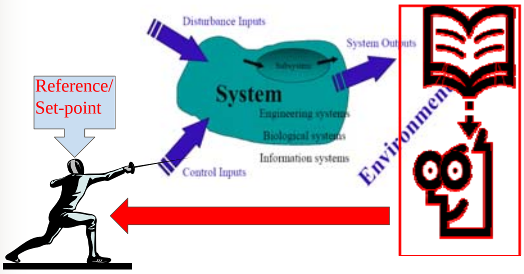
Open-loop Control

- **Open-loop Control:** A control process which does not utilize the feedback mechanism, i.e., the output(s) has no effect upon the control input(s)

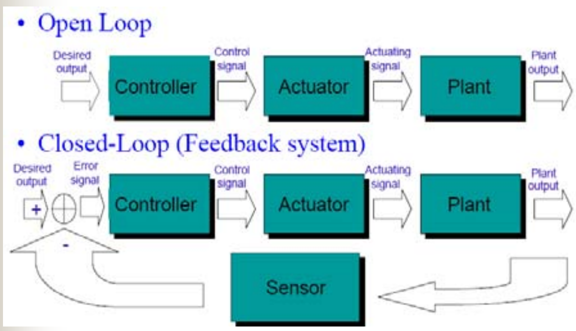


Closed-loop Control

- **Closed-loop Control:** A control process which utilizes the feedback mechanism, i.e., the output(s) does have effect upon the control input(s)

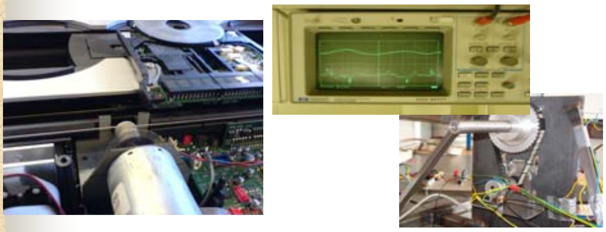


Open-loop vs Closed-loop Control

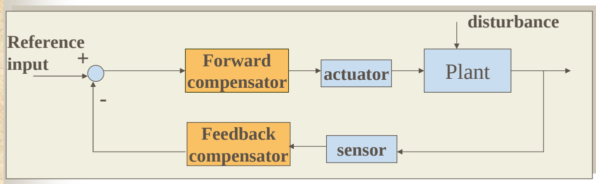


Actuator & Sensor

- **Actuator** is the device that can influence the controlled variable (control input) of the process
- **Sensor** is the device that measure the output variable



Feedback Control



Control system problem:
- **A plant:** a physical system needed to be controlled
- **Specifications:** desired system performance
- **A methodology:** to design a controller such that the closed-loop (feedback control) system satisfies given specifications

→**feedback control theory**

Feedback Control Theory

- Classical control theory (frequency domain)
- Modern control theory (state-space domain)

Specific topics (introduction to advanced control)

robustness | Time delays | Nonlinear | MIMO

Matlab & Simulink

Evolution of Control

Classical control (1940)
- Frequency domain based tools; stability via gain and phase margins
- Mainly useful for single-input, single output (SISO) systems
- Still one of the main tools for the practicing engineer

Modern control (1960)
- "State space" approach to linear control theory
- Works for SISO and multi-input, multi-output (MIMO) systems
- Performance and robustness measures are often not made explicit

Optimal control (1970)
- Find the input that minimizes some objective function (e.g., fuel, time)
- Can be used for open loop or closed loop control (min-time, LQG)

Robust control (1980)
- Generalizes ideas in classical control to MIMO context
- Uses operator theory at its core, but can be easily interpreted in frequency domain

Nonlinear control, adaptive control, hybrid control ...

Control System Design Steps

1. Establish control goals
2. Identify the variables to control
3. Write the specifications for the variables
4. Establish the system configuration and identify the actuator
5. Obtain a model of the process, the actuator, and the sensor
6. Describe a controller and select key parameters to be adjusted
7. Optimize the parameters and analyze the performance

If the performance does not meet the specifications, then iterate the configuration and the actuator.

If the performance meets the specifications, then finalize the design.

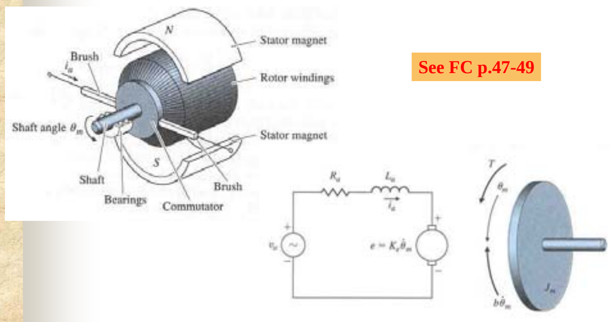
Control System Design Objectives

- Primary objectives:
  1. Dynamic stability
  2. Accuracy
  3. Speed of response
- Additional considerations:
  4. Robustness (insensitivity to parameter variation)
  5. Cost of control
  6. System reliability

Methods to be Covered for Analysis and Design in the Course

- Modeling
  Laplace transforms and transfer functions, state-space model
- Time-domain method
  - Time-domain performance specifications
  - Stability, transient and steady-state responses
- Complex-domain method
  Root locus method for analysis and design of control systems
- Frequency-domain method
  - Frequency-domain performance specifications
  - Nyquist plots and Bode diagrams for analysis and design of control systems
- Analysis and design methods based on state-space models – main topics of the 2nd part of the course

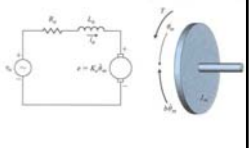
Modeling: DC-motor (I)



See FC p.47-49

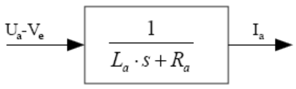
Modeling: DC-motor (II)

- Electrical part:



$$L_a \frac{di_a}{dt} + R_a i_a = v_a - V_e$$

$$V_e = K_e \dot{\theta}_m$$



': Block diagram of the electrical part of the DC-motor.

K_e electromotive force (emf) constant

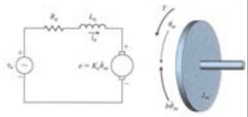
See FC p.47-49

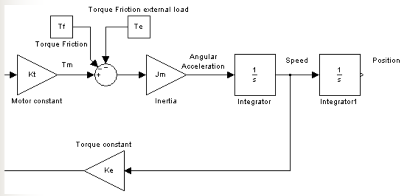
Modeling: DC-motor (III)

- Mechanic Part: K_t torque constant i_a armature current

$$J_m \ddot{\theta}_m + b\dot{\theta}_m = T_m - T_e - T_f$$

$$T_m = K_t i_a$$

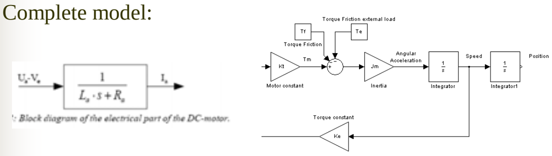


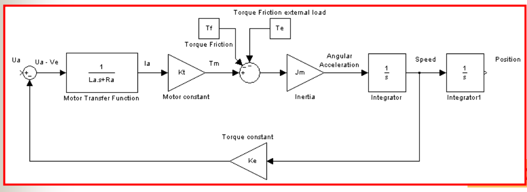


See FC p.47-49

Modeling: DC-motor (IV)

- Complete model:





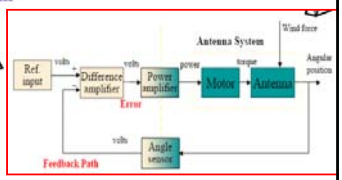
p.47-49

Block Diagram (I)

- **Component block diagram** represents in block form the major components in a control system and shows the major directions of information and energy flow from one component to another

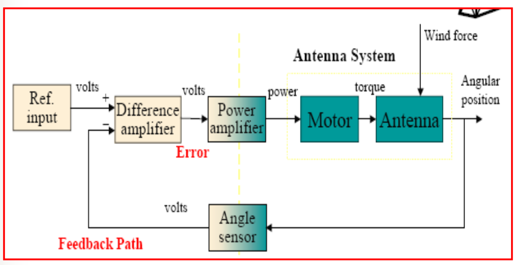
Antenna Positioning Control System

- Original system: the antenna with electric motor drive systems.
- Control objective: to point the antenna in a desired reference direction.
- Control inputs: drive motor voltages.
- Outputs: the elevation and azimuth of the antenna.
- Disturbances: wind, rain, snow.

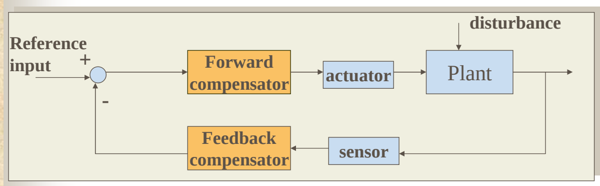


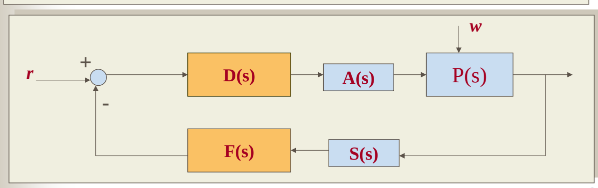
Block Diagram (II)

- **Functional block diagram** illustrated the mathematical relationships between the components in a a control system



Connection – Block Diagrams





System Model: Transfer Function

- **Transfer function description**
  - **Num-den form**

$$G(s)=\frac{Y(s)}{U(s)}=\frac{b_1 s^m+b_2 s^{m-1}+\cdots+b_{m+1}}{a_1 s^n+a_2 s^{n-1}+\cdots+b_{n+1}},\quad e.g.,\quad G(s)=\frac{K}{s^2+2\zeta\omega s+\omega^2}$$

  - **Zero-pole form**

$$G(s)=\frac{Y(s)}{U(s)}=K\frac{\prod_{i=1}^{m}(s-z_i)}{\prod_{i=1}^{n}(s-p_i)}\quad e.g.,\quad G(s)=\frac{K}{(s-p_1)(s-p_2)}$$

Transfer Function **in Matlab/Simulink**

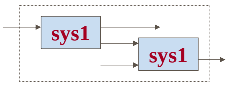
- Num-den transfer function form
  sys=tf(num,den)
- Zero-pole transfer function form
  sys=zpk(Z,P,K)
- Overview of system features
  ltiview(sys)

Connection **in Matlab - I**

- Series connection of two LTIs

sys = series(sys1,sys2)

sys = series(sys1,sys2,outputs1,inputs2)

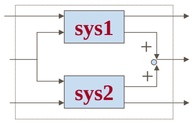


Connection **in Matlab - II**

- Parrallel connection of two LTIs

sys = parallel(sys1,sys2)

sys = parallel(sys1,sys2,inp1,inp2,out1,out2)



Connection **in Matlab - III**

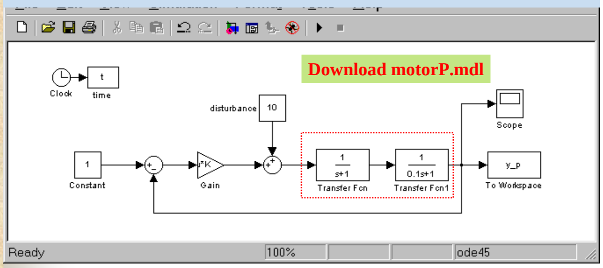
- Feedback connection of two LTIs

sys = feedback(sys1,sys2)

sys = feedback(sys1,sys2,sign)

sys = feedback(sys1,sys2,feedin,feedout,sign)

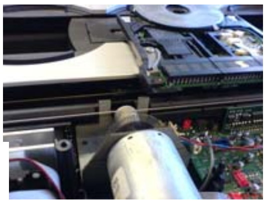
P-Control for the DC Motor



DC Motor Model: $G(s)=\frac{A}{(\tau_1 s+1)(\tau_2 s+1)}$ $\quad \tau_1=1,\quad \tau_2=0.1,\quad A=1$

$K_p=\cdots,\quad e_{ss}=\cdots$

Case study: **BO9000 Sledge Control**



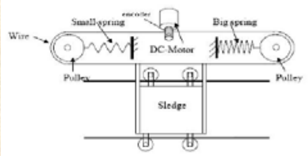


Fig. 3. Schematic diagram of BeoSound 9000 sledge system

After this lecture, you are expected to know

- Some basic concepts in control engineering
  - System, inputs and outputs
  - Open-loop control vs closed-loop control
  - (automatic) feedback control
  - Transfer function description
- Block diagram decription
- How to start system construction in Matlab/simuink

Execise one

- Start the preliminary analysis of your project system
  - Objectives
  - Considereds system (plant), control input(s), output(s), disturbance input(s)
  - Actuator(s) and its driver(s)
  - Need feedback control?
  - Sensor(s) and its driver(s)
  - Potential platform for control implementation

  If possible,
  - Derive the component block diagram of your consided system
  - sketch the functional block diagram of your consided system
  - Start to be familiar with Matlab/Simulink