# Grundlæggende Regulering og Modellering (II)
# -
# Fundamental Control Theory and Modelling (II)

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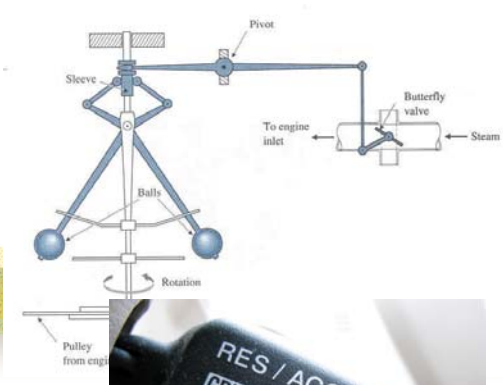
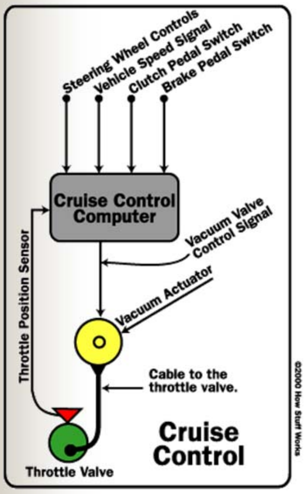
## Preface

What's that?




# Cruise Control Systems




- Why?
- How?

- http://auto.howstuffworks.com/cruise-control3.htm



**Titel:**
B4-3 Grundlæggende regulering og modellering / Fundamental Control Theory and Modelling

**Mål:**
Studerende der gennemfører modulet:

*Viden:*

- Skal have viden om modellering af fysiske systemer, bestemmelse af arbejdspunkter og linearisering
- Skal have forståelse for et systems dynamiske og stationære opførsel, herunder indflydelsen af systemets type og orden, samt poler og nulpunkter og deres indflydelse på systemets respons
- Skal have forståelse for analyse vha. rodkurver og viden om regulatordesign vha. rodkurver
- Skal have forståelse for et systems frekvensrespons (åben-sløjfe og lukket-sløjfe)
- Skal have forståelse for relativ stabilitet
- Skal have forståelse for design vha. frekvensresponsteknikker
- Skal have viden om analog implementering af regulatorer
- Skal have viden om måleteknik og dataopsamling vha en PC
- Skal have viden om software til opbygning/udvikling af programmer til dataopsamling og regulering på mekaniske/elektriske systemer
- Skal have viden om målekædens opbygning og virkemåde (dvs sensor, signal behandling og indikator)
- Skal have viden om klassiske sensorers virkemåde (tryk, temperatur, position, hastighed, acceleration, flow)
- Skal have viden om sampling, forskellige opkoblinger og målestøj

# Ultimate objective

- To enable students to apply basic classical control techniques to analyze, design and implement a control system



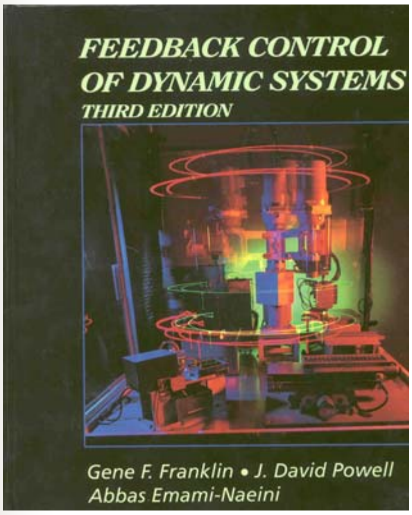
# Teachers

**Grundlæggende regulering og modellering:**

- Leif Wagner Jørgensen, lwj@bio.aau.dk
- Zhenyu Yang, yang@et.aau.dk

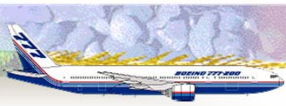
- B.Sc. (1991), M.Sc.(1994), Control Theory
- PhD. EE (1997), BUAA
- Postdoctor (1998), EE, TU Delft
- Joined AAU at 1999
- Associate Prof., ET, AAU
- Coordinator of ED5-6 semesters, and Intelligent Reliable Systems (IRS) master program

# Textbook (Zhenyu's part)



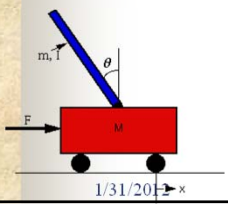

**6th edition!**

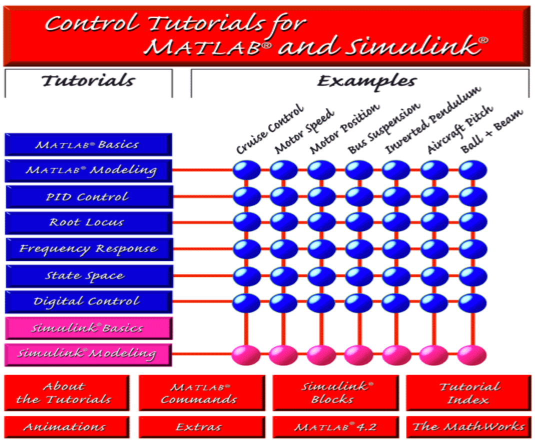




# Control Tutorials for Matlab

- **http://www.library.cmu.edu/ctms/**



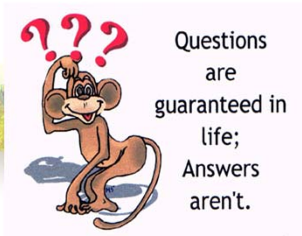



# Content (10 lectures)

- **MM1:** Introduction to control engineering
- **MM2:** Essentials for feedback control
- **MM3:** Responses of dynamic systems
- **MM4:** PID control
- MM8: Performance and stability analysis
- MM5: frequency response analysis
- MM6: frequency response design
- MM7: Root locus method
- MM9: Essentials to digital control
- MM10: Practical issues and case studies



# Questions?




http://jlwylie.wordpress.com/2011/02/12/brainstorm-interesting-author-interview-questions/

# MM1 Introduction to Control Engineering

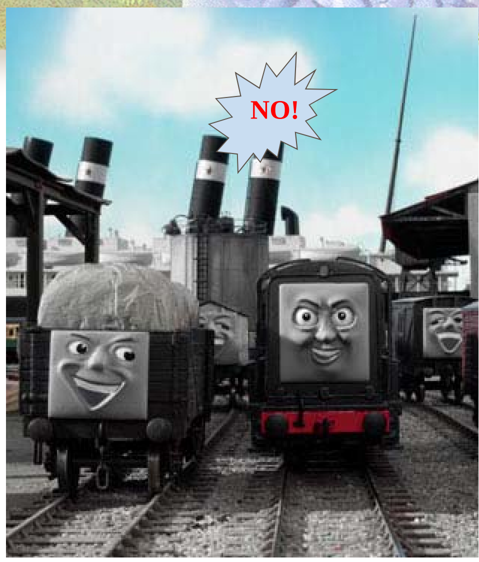
Readings:

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

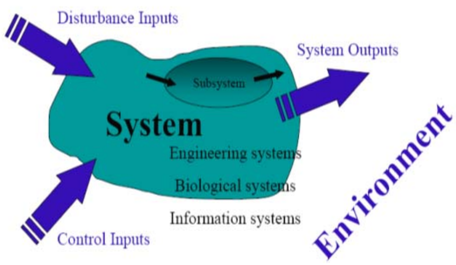




http://www.thomasandfriends.com/uk/thomas.asp



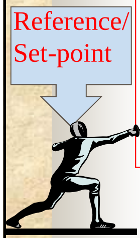
## Basic Concept (I): **System and its Variables**

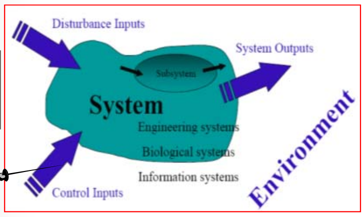
- A **system** is a collection of components which are coordinated together to perform a function
- Systems interact with their **environment**. The interaction is defined in terms of **variables**
  - System inputs
  - System outputs
  - Environmental disturbances
- **Dynamic system** is a system ehose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

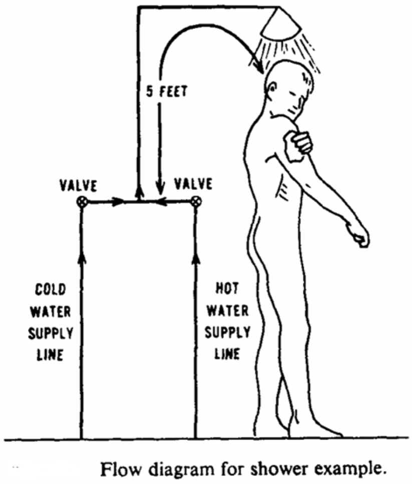


## Basic Concept (II): **Control**

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



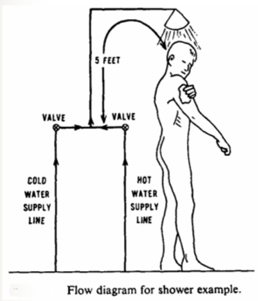






## Basic Concept (III): **Manual Control**

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



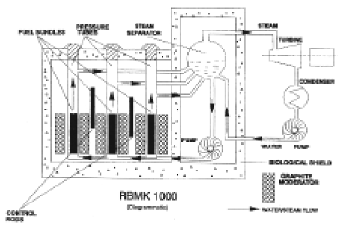

## Manual Control: **Safety issue (I)**

- **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



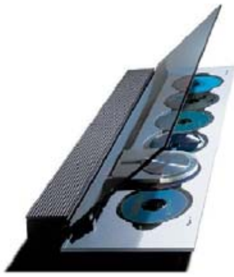

On 26 April 1986

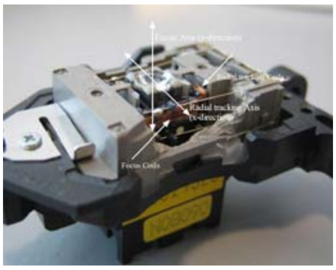
The result of a flawed reactor design that was operated with inadequately trained personnel and without proper regard for **safety**

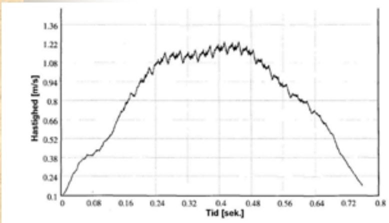
31 people were killed, and there have since been around 10 deaths from thyroid cancer due to the accident

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

## Manual Control: **Slow Response**



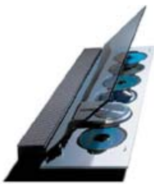





Figur 4: Viser gammel motors hastighedsprofil ved vandret placering



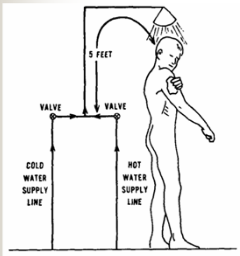
## Manual Control: **Comfortness**



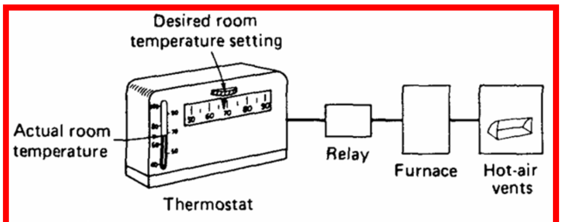
## Basic Concept (IV): **Automatic Control**

- **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)



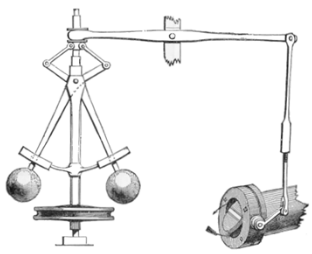
Flow diagram for shower example.



Home heating control system.



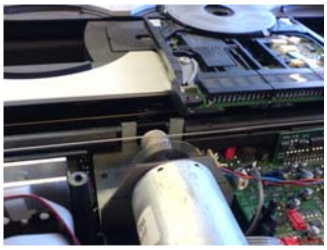
## Automatic Control: **Cruise Control** (Speed control)



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

Boulton & Watt engine of 1788

# Automatic Control: **BO9000 Sledge Control**



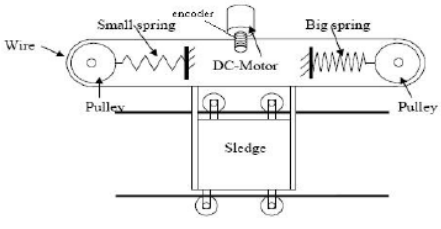
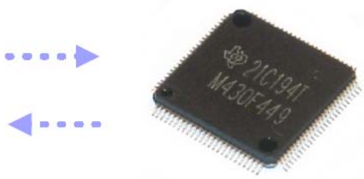
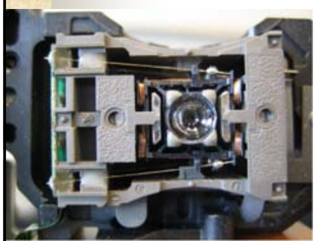


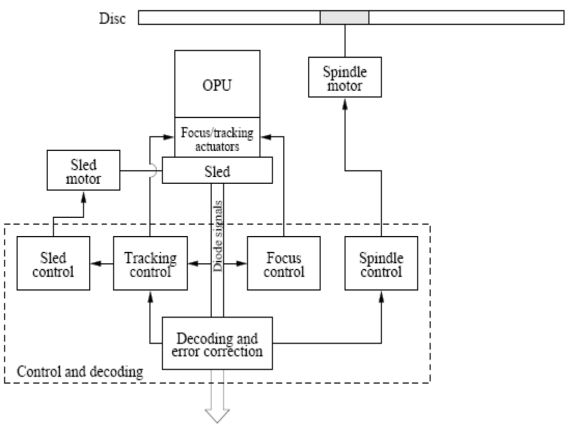

Fig. 3. Schematic diagram of BeoSound 9000 sledge system





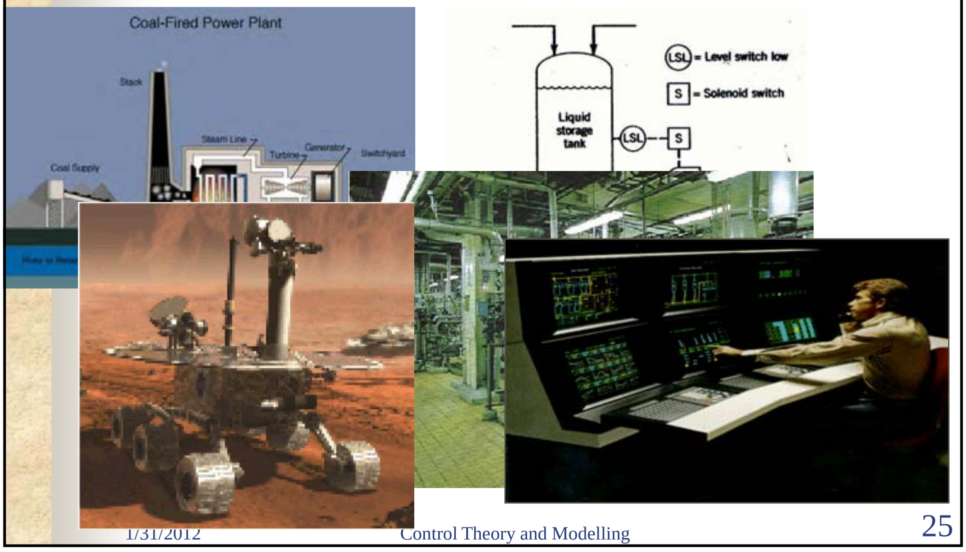
# Automatic Control: **OPU Position Control**






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

## Automatic Control: **Process Control**



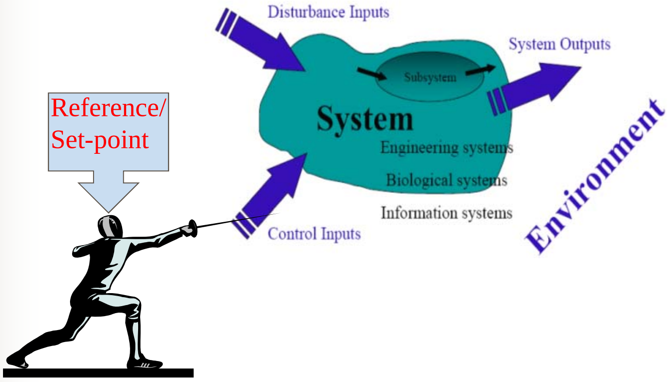



## Control Classification

- **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)

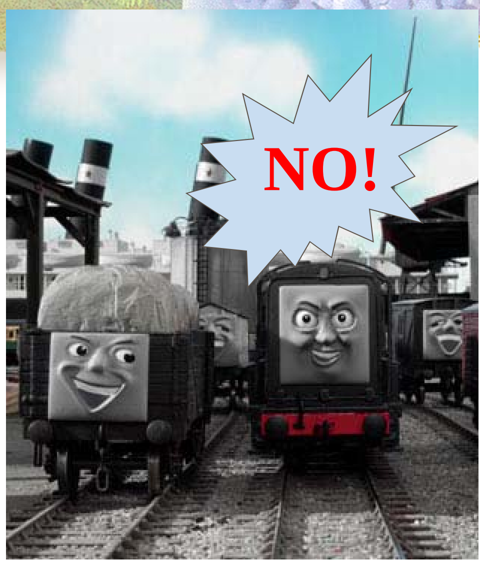
# Open-loop Control

- **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)





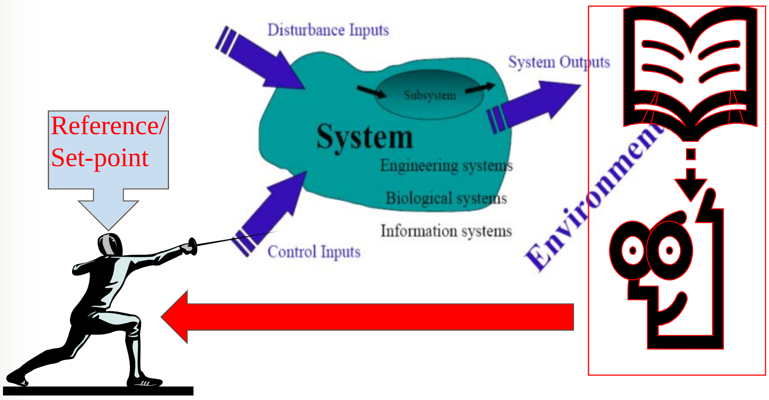





http://www.thomasandfriends.com/uk/thomas.asp

# Closed-loop Control

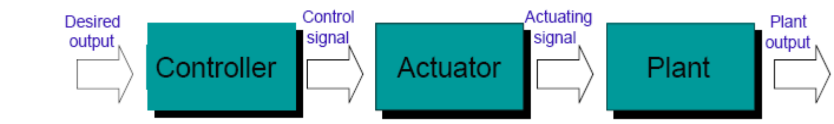
- **Closed-loop Control:** A control process which utilizes the feedback mechanism, i.e., the output(s) does have effect upon the control input(s)



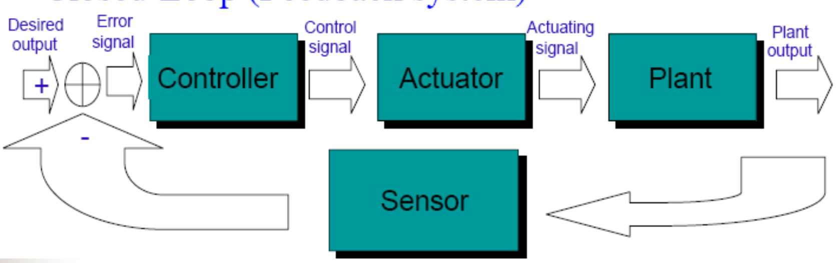



# Open-loop vs Closed-loop Control

- Open Loop

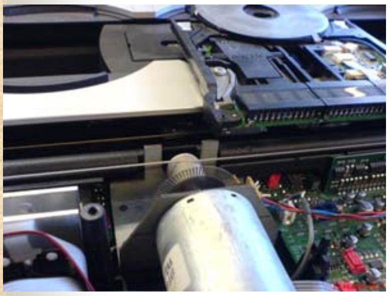



- Closed-Loop (Feedback system)



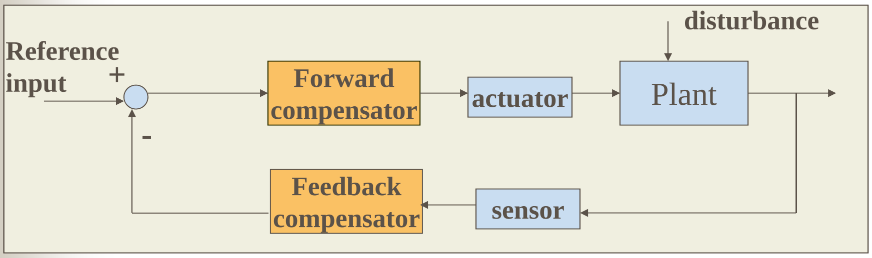
# Actuator & Sensor

- **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

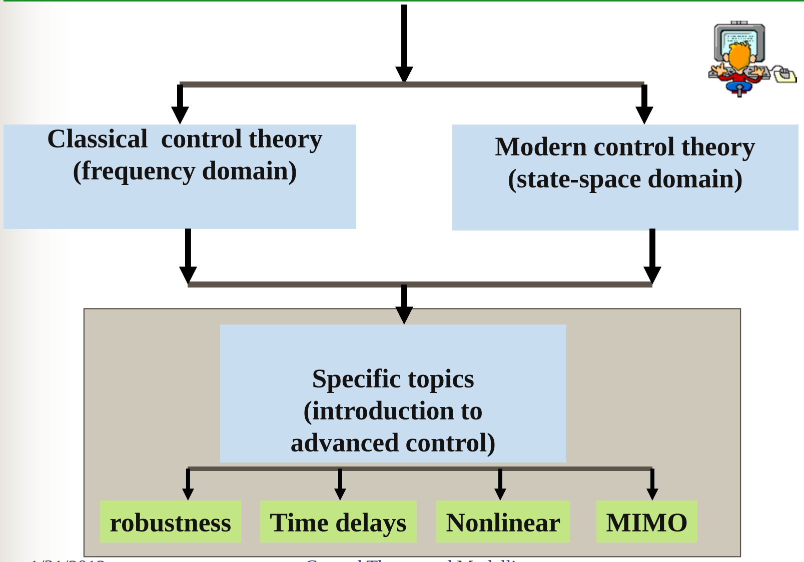



**Control system problem:**

- **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




Matlab & Simulink



# Evolution of Control

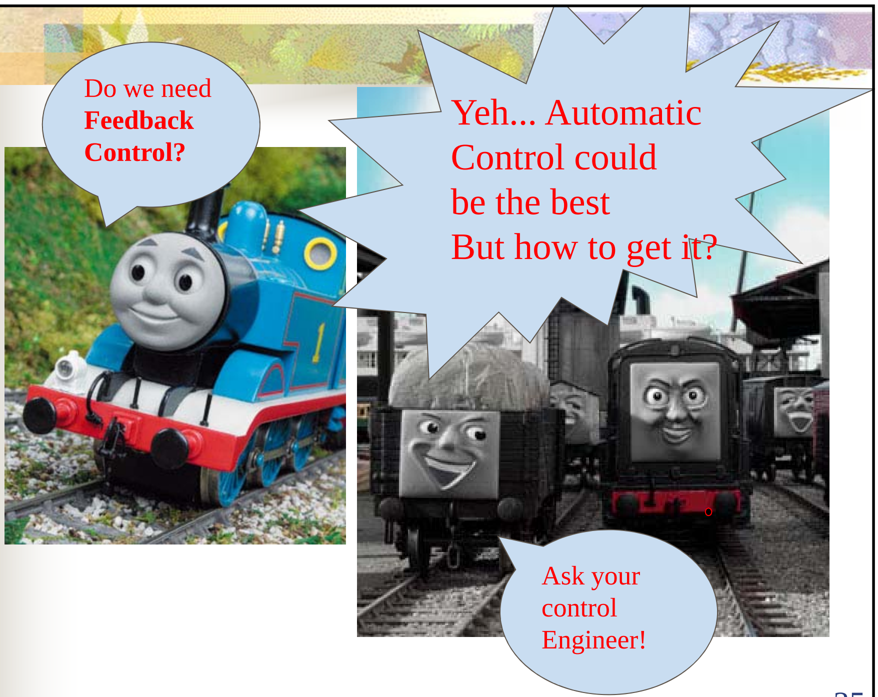
**Classical control** 1940
- Frequency domain based tools; stability via gain and phase margins
- Mainly useful for single-input, single output (SISO) systems
- Still one of the main tools for the practicing engineer

**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 ...**

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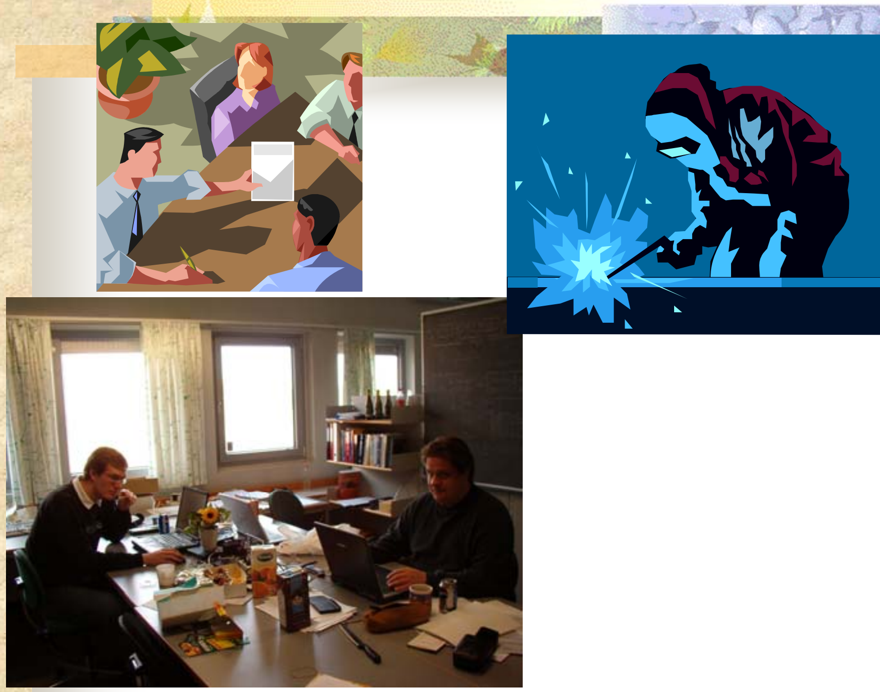

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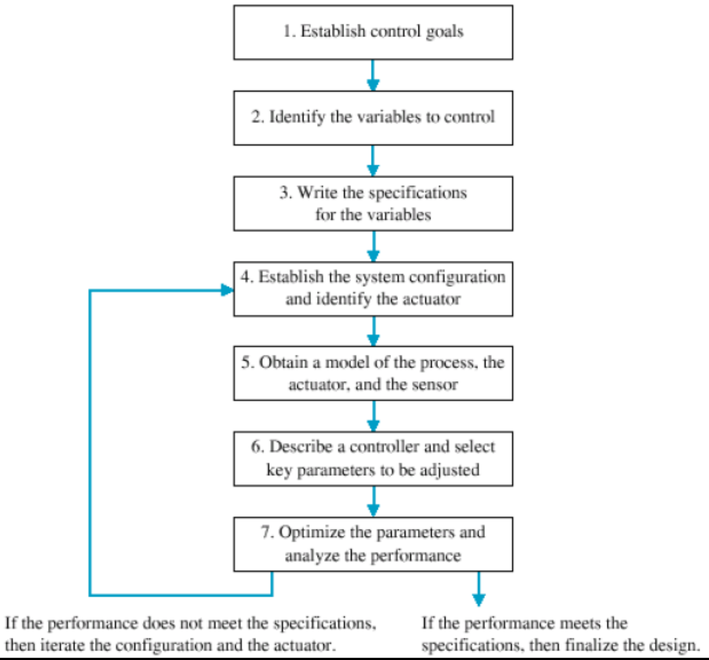
# Control System Design Steps






# 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

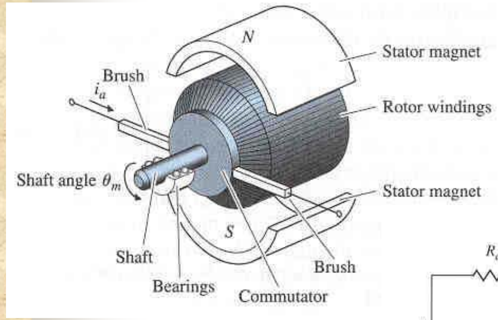
## Methods to be Covered for Analysis and Design in the Course

- 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

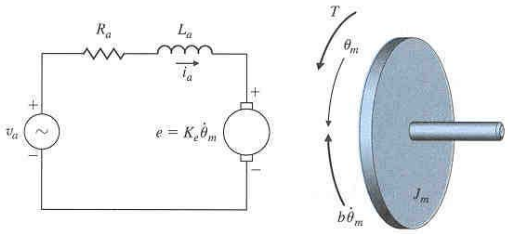


## Models and modeling: Example

# Modeling: DC-motor (I)



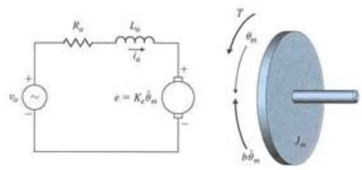

See FC p.47-49





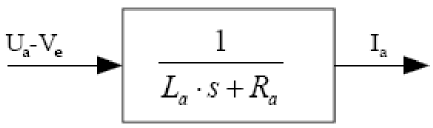

# Modeling: DC-motor (II)

- 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

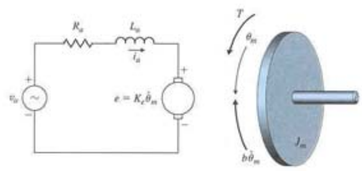
See FC p.47-49

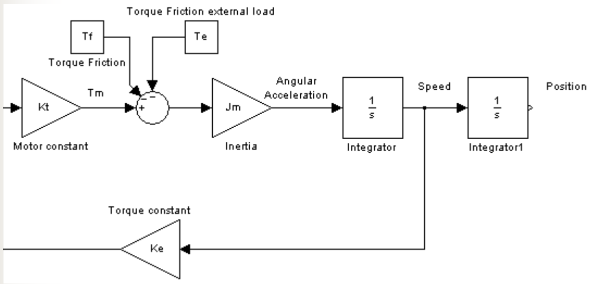
# Modeling: DC-motor (III)

- Mechanic Part: **$K_t$** torque constant **$i_a$** armature current

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

$$T_m = K_t i_a$$



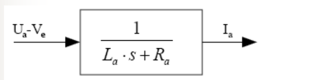



**See FC p.47-49**

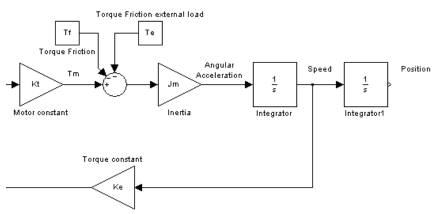


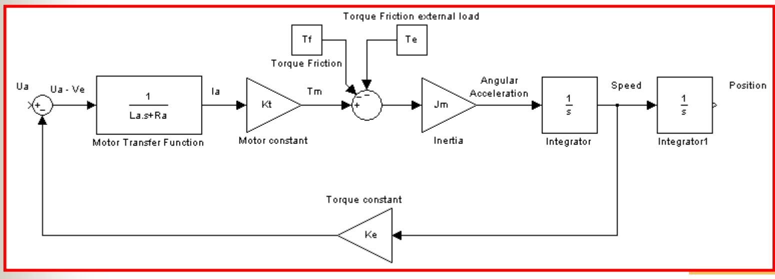
# Modeling: DC-motor (IV)

- Complete model:




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



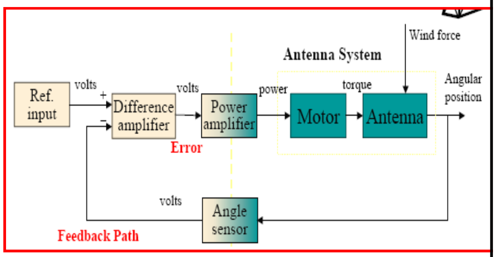

**p.47-49**

# 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

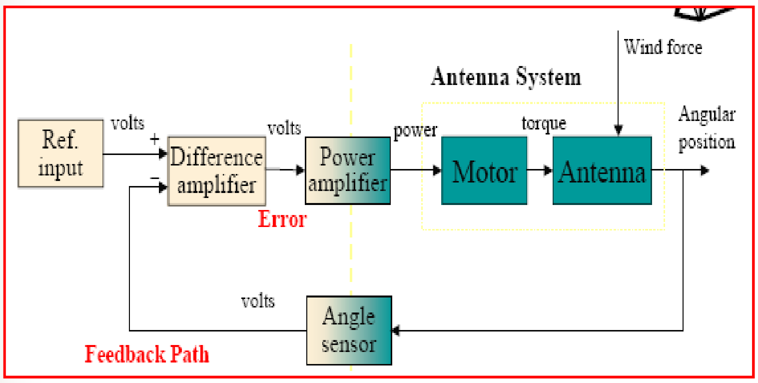
- Original system: the antenna with electric motor drive systems.
- Control objective: to point the antenna in a desired reference direction.
- Control inputs: drive motor voltages.
- Outputs: the elevation and azimuth of the antenna.
- Disturbances: wind, rain, snow.



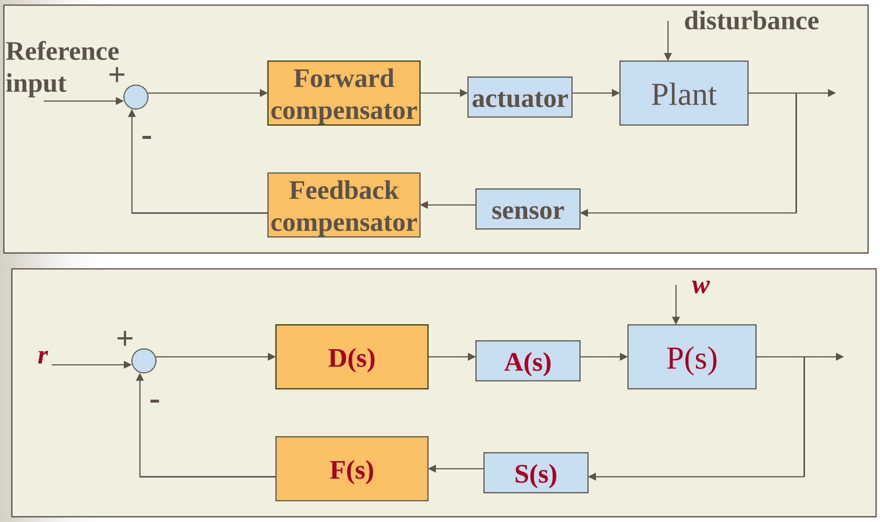



# Block Diagram (II)

- **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)**

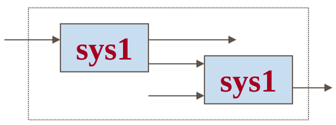


## Connection **in Matlab - I**

- Series connection of two LTIs

**sys = series(sys1,sys2)**

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

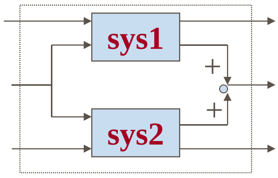


# Connection in Matlab - II

- Parrallel connection of two LTIs

**sys = parallel(sys1,sys2)**

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






# Connection in Matlab - III

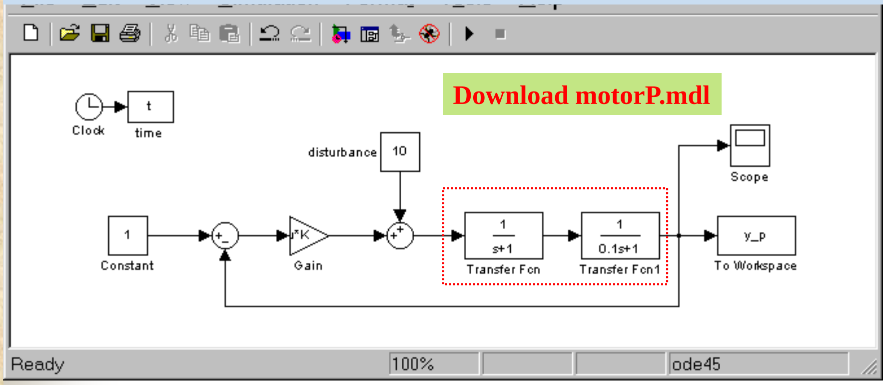
- Feedback connection of two LTIs

**sys = feedback(sys1,sys2)**

**sys = feedback(sys1,sys2,sign)**

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

# P-Control for the DC Motor

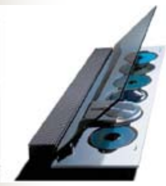



DC Motor Model: $G(s) = \dfrac{A}{(\tau_1 s + 1)(\tau_2 s + 1)}$ $\quad \tau_1 = 1, \quad \tau_2 = 0.1, \quad A = 1$

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



# Case study: **BO9000 Sledge Control**



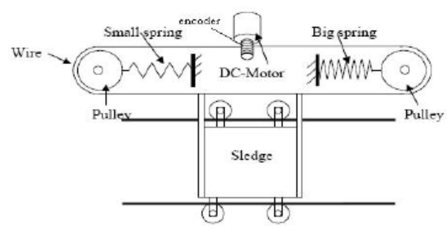
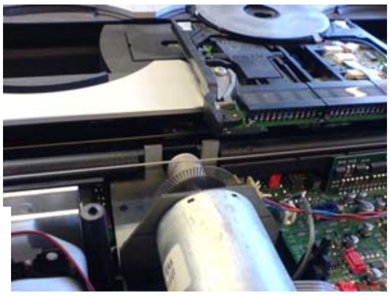



Fig. 3. Schematic diagram of BeoSound 9000 sledge system



# 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