Introduction to Robotics

Lecture 9

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Technical Aspects of Multimodal Systems

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Outline

Outline (cont.)

Classification of Robot Arm Controllers
Internal Sensors of Robots
Control System of a Robot

Definitions

Controller

- Influences one or more physical variables
  - meet a control variable
  - reduce disturbances
- Compares actual value to reference value
  - minimize control deviation

Definitions (cont.)

System

- Physical or technical construct
  - input signal – stimulus
  - output signal – response
- Transforms stimulus into response
- Symbolical illustration
  - block with marked signals
  - direction of signal effect expressed with arrows

Definitions (cont.)

Input and output variables

- Change over time
    - expressed as $u(t)$ and $v(t)$ (dynamic system)
- Infinite number of possible variables
    - for real-world dynamic technical systems (in principle)
- Description of system behaviour based on desired application
    - using the relevant variables

Control Problem

Given: dynamic system (to be controlled)

- Model describing dynamic system (e.g. jacobian)
- Input variables – control variables
  - measured values (sensor data)
- Output variables – controlled variables
  - system input (force/torque data)

Control Problem (cont.)

Problem

- Keep control variable values constant or
- Follow a reference value or
- Minimize the influence of disturbances

Sought: controller (for dynamic system)

- Implement hardware or software controller
- Alter controlled-variables (output)
- Based on control variables (input)
- Solve the problem

Example: Cruise Control

Input

- Speed over ground
- Relative speed to traffic
- Distance to car in front
- Distance to car behind
- Weather conditions
- Relative position in road lane
- ...

Output

- Throttle
- Brakes
- Steering

Development of Control Engineering - Timeline

1788 J. Watt: engine speed governor

1877 J. Routh: differential equation for the description of control processes

1885 A. Hurwitz: stability studies

1932 A. Nyquist: frequency response analysis

1940 W. Oppelt: frequency response analysis, Control Engineering becomes an independent discipline

1945 H. Bode: discipline new methods for frequency response analysis

1950 N. Wiener: statistical methods

1956 L. Pontrjagin: optimal control theory, maximum principle

Development of Control Engineering - Timeline (cont.)

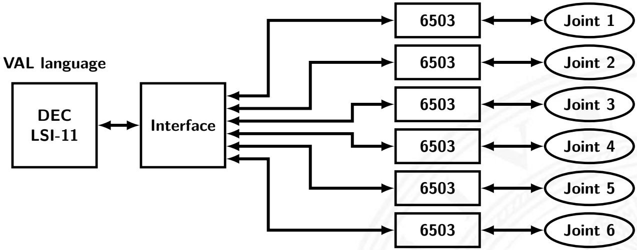
1957	R. Bellmann: dynamic programming
1960	direct digital control
1965	L. Zadeh: Fuzzy-Logic
1972	Microcomputer use
1975	Control systems for automation
1980	digital device technology
1985	Fuzzy-controller for industrial use
1995	artificial neuronal networks for industrial use

Classification of Robot Arm Controllers

As the problem of trajectory-tracking:

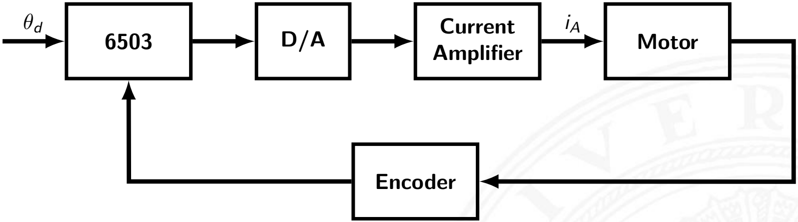
- Joint space: PID, plus model-based
- Cartesian space: joint-based
  - using kinematics or using inverse Jacobian calculation
- Adaptive: model-based adaptive control, self-tuning
  - controller (structure and parameter) adapts to the time-invariant or unknown system-behavior
  - basic control circle is superimposed by an adaptive system
  - process of adaption consists of three phases
    - identification
    - decision-process
    - modification
- Hybrid force and position control is still a current research topic

Control System Architecture of PUMA-Robot



- 2-level hierachical structure of control system
- *DEC LSI-11* sends joint values at 35.7 Hz (28 ms)
  - trajectory
- Distance of actual value to goal value is interpolated
  - using 8,16,**32** or 64 increments

Control System Architecture of PUMA-Robot (cont.)



- The joint control loop operates at 1143 Hz (0.875 ms)
- Encoders are used as position sensors
- Potentiometer are used for rough estimation (only PUMA-560)
- No dedicated speedometer
    - velocity is calculated as the difference of joint positions over time

Internal Sensors of Robots

- Placed inside the robot
- Monitor the internal state of the robot
  - e.g. position and velocity of a joint

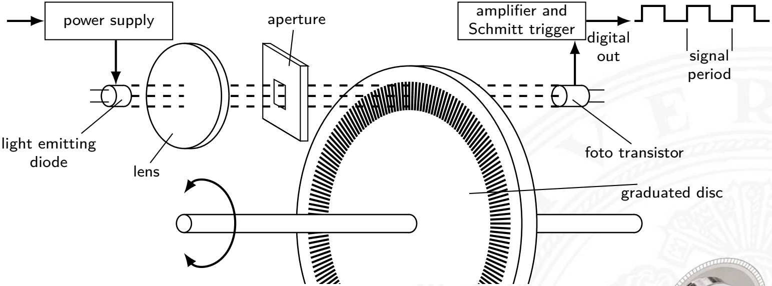
Position measurement systems

- Potentiometer
- Incremental/absolute encoder
- Resolver

Velocity measurement systems

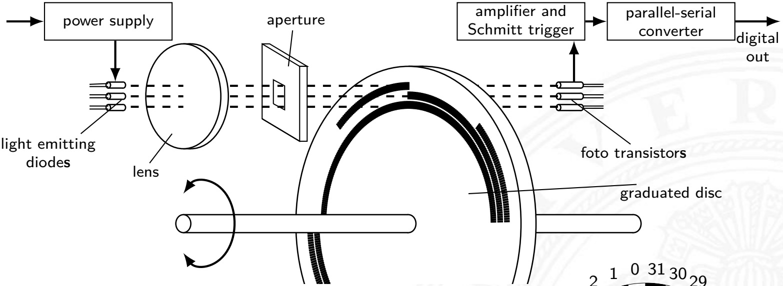
- Speedometers
- Calculate from position change over time

Optical Incremental Encoders

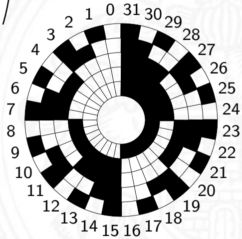


- An optical encoder reads the lines
- The disc is mounted to the shaft of the joint motor
  - PUMA-560: 1:1 ratio; .0001 rad/bit accuracy
- one special line is marked as the “zero-position”

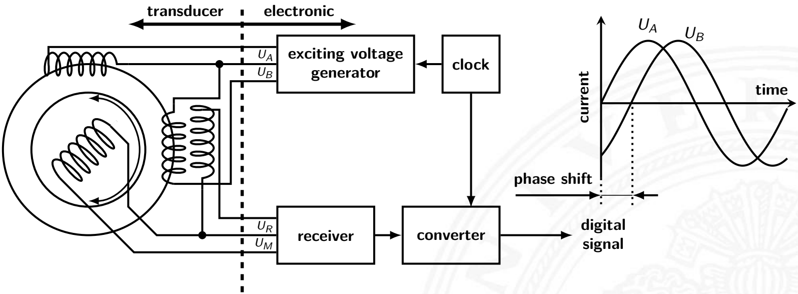
Optical Absolute Encoder



- multiple LEDs and foto transistors
- e.g. 5 bit dual code gives 32 angular positions and 11.25° resolution
- parallel-serial converter required
- absolute positioning and direction

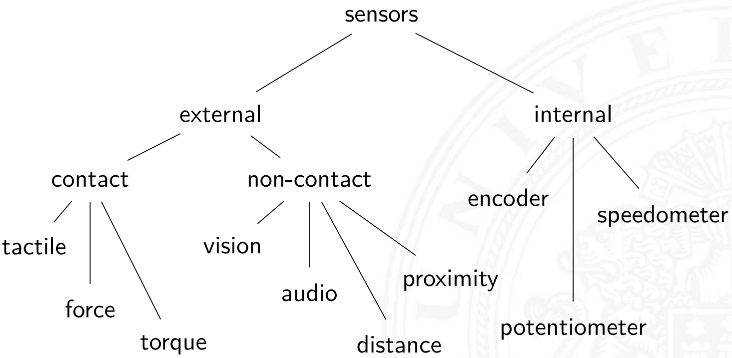


Resolver

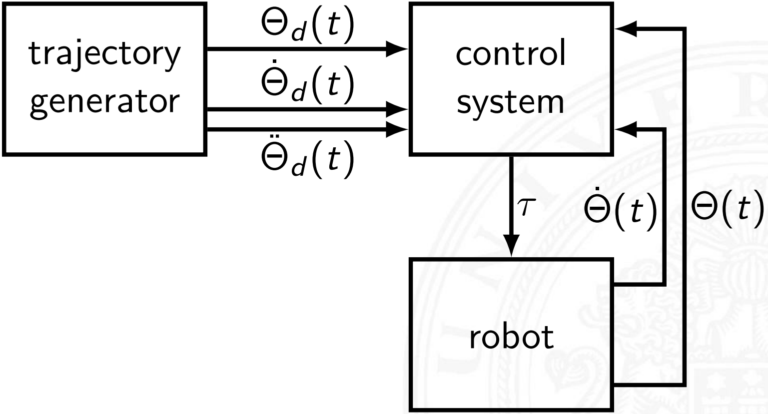


- analog rotation encoding
- phase shift between U_A and U_B determines rotation
- precision depending on digital converter

Sensor Classification Hierarchy



Control System of a Robot



trajectory generator

$\Theta_d(t)$

$\dot{\Theta}_d(t)$

$\ddot{\Theta}_d(t)$

control system

τ

$\dot{\Theta}(t)$

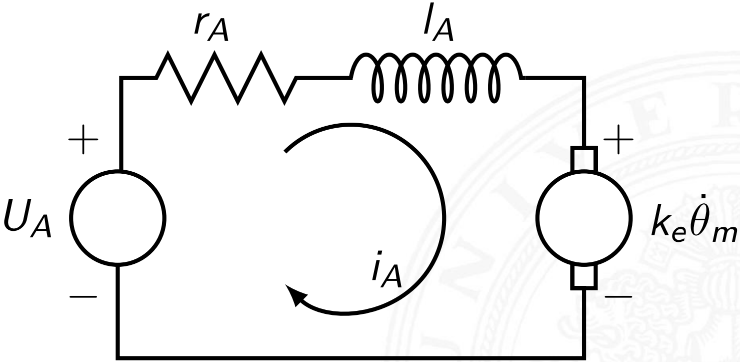
$\Theta(t)$

robot

Control System of a Robot (cont.)

- Target values
  - $\Theta_d(t)$
  - $\dot{\Theta}_d(t)$
  - $\ddot{\Theta}_d(t)$
- Magnitude of error
  - $E = \Theta_d - \Theta, \dot{E} = \dot{\Theta}_d - \dot{\Theta}$
- Output value
  - $\Theta(t)$
  - $\dot{\Theta}(t)$
- Control value
  - τ

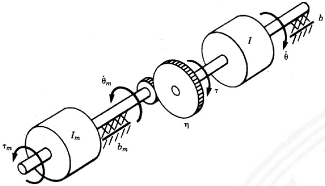
Circuit of a DC-Motor



The circuit can be described with the first order differential equation:

$$l_a \dot{i}_a + r_a i_a = v_a - k_e \dot{\theta}_m$$

Connection Between Motor and a Joint



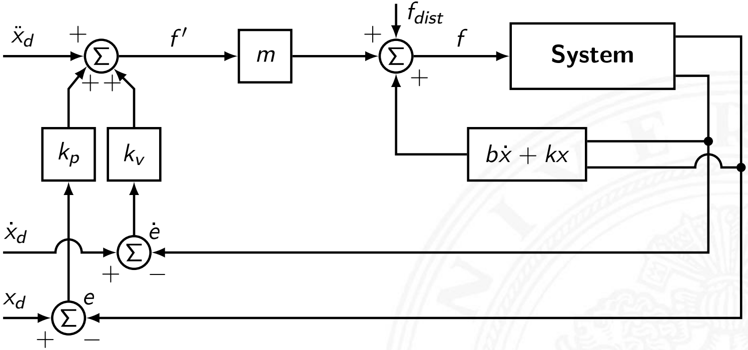
Let η be the transmission ratio, then:

$$\tau_m = (I_m + I/\eta^2)\ddot{\theta}_m + (b_m + b/\eta^2)\dot{\theta}_m$$

where $\tau_m = k_m i_a$, I_m and I are the inertia of the rotor (inside motor) and the load, b_m and b are factors for friction.
Expressed with joint variables:

$$\tau = (I + \eta^2 I_m)\ddot{\theta} + (b + \eta^2 b_m)\dot{\theta}$$

Linear Control for Trajectory Tracking



$$f' = \ddot{x}_d + k_v\dot{e} + k_p e + k_i \int e dt \tag{89}$$

is called the principle of PID-control.

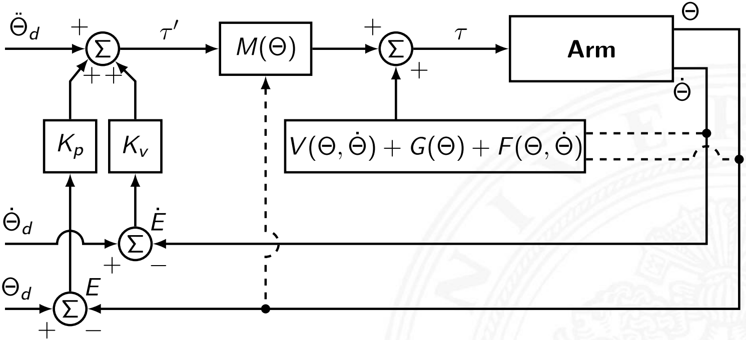
P I D-Controller

- P Proportional controller: $\tau(t) = k_p \cdot e(t)$
  The amplification factor k_p defines the sensitivity.
- I Integral controller: $\tau(t) = k_i \cdot \int_{t_0}^{t} e(t')dt'$
  Long term errors will sum up.
- D Derivative controller: $\tau(t) = k_v \cdot \dot{e}(t)$
  This controller is sensitive to changes in the deviation.

Combined ⇒ PID-controller:

$$\tau(t) = k_p \cdot e(t) + k_v \cdot \dot{e}(t) + k_i \int_{t_0}^{t} e(t')dt'$$

Model-Based Control for Trajectory Tracking



The dynamic equation: $\tau = M(\Theta)\ddot{\Theta} + V(\Theta,\dot{\Theta}) + G(\Theta)$

where $M(\Theta)$ is the position-dependent $n \times n$-mass matrix of the manipulator, $V(\Theta,\dot{\Theta})$ is a $n \times 1$-vector of centripetal and Coriolis factors, and $G(\Theta)$ is a complex function of Θ, the position of all joints of the manipulator.

Robot Control Improvements

Scientific Research

- model-based control
- adaptive control

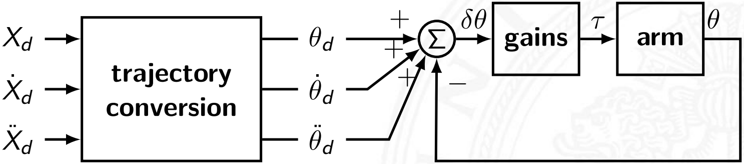
Industrial robotcs

- PID-control system with gravity compensation

$$\tau = \dot{\Theta}_d + K_v \dot{E} + K_p E + K_i \int E dt + \hat{G}(\Theta)$$

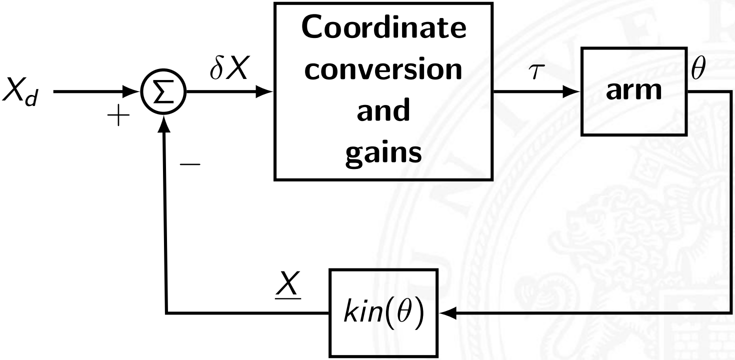
Control in Cartesian Space – Method I

Joint-based control with Cartesian trajectory input



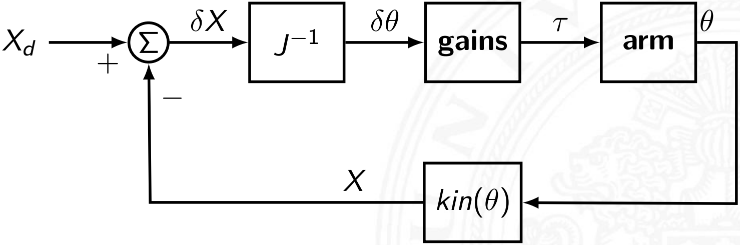
Control in Cartesian Space – Method II

Cartesian control via calculation of kinematics



Control in Cartesian Space – Method III

Cartesian control via calculation of inverse Jacobian



Hybrid Control of Force and Position

Motivation

Certain tasks require control of both: position and force of the end-effector:

- assembly
- grinding
- opening/clsoing doors
- crank winding
- . . .

An examples shows two feedback loops for seperate control of position and force

Hybrid Control of Force and Position (cont.)