ACTUATORS AND SENSORS

Joint actuating system

Servomotors

Sensors
JOINT ACTUATING SYSTEM
Transmissions

- Joint motion
  - low speeds
  - high torques

- **Spur gears**
  - change axis of rotation and/or translate application point
  - wide cross-section teeth and squat shafts

- **Lead screws**
  - convert rotational motion into translational motion
  - ball screws usually preloaded (increase stiffness and decrease backlash)

- **Timing belts**
  - employed to locate motor remotely from axis of actuated joint
  - high speeds and low forces (stress may cause strain)

- **Chains**
  - employed to locate motor remotely from axis of actuated joint
  - low speeds (vibration)
• *Direct drive*
  
  ★ no elasticity and backlash
  ★ more sophisticated control algorithms
Servomotors

- **Pneumatic motors**
  - Pneumatic energy provided by compressor, transformed into mechanical energy by means of pistons or turbines

- **Hydraulic motors**
  - Hydraulic energy stored in reservoir transformed into mechanical energy by means of suitable pumps

- **Electric motors**
  - Electric energy available from distribution system
• Motors for industrial robots
  ⚫ low inertia and high power-to-weight ratio
  ⚫ possibility of overload and delivery of impulse torques
  ⚫ capability to develop high accelerations
  ⚫ wide velocity range (from 1 to 1000 revolutes/min)
  ⚫ high positioning accuracy (at least 1/1000 of a circle)
  ⚫ low torque ripple so as to guarantee continuous rotation even at low speed

• Servomotors
  ⚫ trajectory tracking
  ⚫ positioning accuracy

• Electric servomotors
  ⚫ permanent-magnet direct-current (DC) servomotors
  ⚫ brushless DC servomotors
  ⚫ stepper motors (micromanipulators)

• Hydraulic servomotors
  ⚫ linear pistons (translational motions)
  ⚫ axial or radial pistons (rotational motions)
• Electric servomotors

Pros:

★ widespread availability of power supply
★ low cost and wide range of products
★ high power conversion efficiency
★ easy maintenance
★ no pollution of working environment

Cons:

★ burnout problems at static situations caused by the effect of gravity on the manipulator (emergency brakes are required)
★ need for special protection when operating in flammable environments
• Hydraulic servomotors

*do not suffer from burnout in static situations

* are self-lubricated and the circulating fluid facilitates heat disposal

* are inherently safe in harmful environments

* have excellent power-to-weight ratios

Cons:

* need for a hydraulic power station

* high cost, narrow range of products, and difficulty of miniaturization

* low power conversion efficiency

* need for operational maintenance

* pollution of working environment due to oil leakage
• Electric servomotors
  ⋆ good dynamic behaviour
  ⋆ excellent control flexibility
  ⋆ need for transmissions

• Hydraulic servomotors
  ⋆ dynamic behaviour depending on temperature of compressed fluid
  ⋆ high torques at low speeds
Power amplifiers

• Task of modulating power flow from primary supply (under action of control signal)

• Electric servomotors
  * transistor amplifiers
    DC-to-DC controlled converters (choppers)
    DC-to-AC controlled converters (inverters)

• Hydraulic servomotors
  * electro–hydraulic servovalve
Power supply

- Electric servomotors
  - transformer and (uncontrolled) bridge rectifier

- Hydraulic servomotors
  - pump driven by primary motor (three-phase nonsynchronous motor) operating at constant speed + reservoir + filters + pressure and check valves
ELECTRIC DRIVES

- Electric balance
  \[ V_a = (R_a + sL_a)I_a + V_g \]
  \[ V_g = k_v \Omega \]

- Mechanical balance
  \[ C_m = (sI_m + F_m) \Omega + C_r \]
  \[ C_m = k_t I_a \]

- Power amplifier
  \[ \frac{V_a}{V_c} = \frac{G_v}{1 + sT_v} \]

- Current feedback
- Velocity-controlled generator

- $k_i = 0$
- $F_m \ll k_v k_t / R_a$
- $K = C_i(0) G_v$
- $C_r = 0$

$$\Omega = \frac{K}{k_v} \frac{1}{1 + s \frac{R_a I_m}{k_v k_t}} v_c' - \frac{R_a}{k_v k_t} \frac{1}{1 + s \frac{R_a I_m}{k_v k_t}} C_r$$

- at steady state:

$$\omega \approx \frac{K}{k_v} v'_c$$
• Current protection
• Torque-controlled generator

\[ \frac{k_t}{k_i} \]

\[ C_m \]

\[ \frac{1}{sI_m + F_m} \]

\[ V_c' \]

\[ \frac{1}{sI_m + F_m} \]

\[ \Omega_m \]

\[ \ast Kk_i \gg R_a \]

\[ \ast k_v \Omega / Kk_i \approx 0 \]

\[ \Omega = \frac{k_i}{1 + s \frac{I_m}{F_m}} V_c' - \frac{1}{1 + s \frac{I_m}{F_m}} C_r \]

\[ c_m \approx \frac{k_t}{k_i} \left( v_c' - \frac{k_v}{K} \omega \right) \]

\[ c_m \approx \frac{k_t}{k_i} \left( v_c' - \frac{k_v}{K} \omega \right) \]
Transmission effects

- Mechanical balances at motor side and load side

\[ c_m = I_m \dot{\omega}_m + F_m \omega_m + f r_m \]
\[ f r = I \dot{\omega} + F \omega + c_l \]

\[ \downarrow \]

\[ c_m = I_{eq} \dot{\omega}_m + F_{eq} \omega_m + \frac{c_l}{k_r} \]

\[ I_{eq} = \left( I_m + \frac{I}{k_r^2} \right) \]
\[ F_{eq} = \left( F_m + \frac{F}{k_r^2} \right) \]

- Pendulum actuated via mechanical gear

\[ c_m = I_{eq} \dot{\omega}_m + F_{eq} \omega_m + \left( \frac{m g \ell}{k_r} \right) \sin \left( \frac{\varphi_m}{k_r} \right) \]
Position control

- Electric drive control
  - independent joint motion
• Position feedback

\[ \Theta_r \rightarrow K_P \frac{1 + s T_P}{s} \rightarrow + \rightarrow k_{TP} \rightarrow \frac{k_m}{1 + s T_m} \rightarrow \Omega_m \rightarrow \frac{1}{s} \rightarrow \Theta_m \]

\[ \frac{DR_p}{k_t} \]

• Position and velocity feedback

\[ \Theta_r \rightarrow K_P \rightarrow - \rightarrow K_v \frac{1 + s T_v}{s} \rightarrow + \rightarrow k_{TV} \rightarrow \frac{k_m}{1 + s T_m} \rightarrow \Omega_m \rightarrow \frac{1}{s} \rightarrow \Theta_m \]
SENSEORS

- **Proprioceptive** sensors
  - joint positions
  - joint velocities
  - joint torques

- **Exteroceptive** sensors
  - force sensors
  - tactile sensors
  - proximity sensors
  - range sensors
  - vision sensors
  - sensors for specific applications (sound, humidity, smoke, pressure, temperature)

sensory data fusion (robot ≡ intelligent connection of perception to action)
Position transducers

• Linear displacements (measuring robots)
  ★ potentiometers
  ★ linear variable–differential transformers (LVDT)
  ★ inductosyns

• Angular displacements
  ★ potentiometers
  ★ encoders
  ★ resolvers
  ★ synchros
• Absolute encoder

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• Incremental encoder

• Reconstruction of velocity (pulse generated at each transition)
  ∗ voltage-to-frequency converter (analog output)
  ∗ frequency measurement (digital)
  ∗ sampling time measurement (digital)
• Resolver
Velocity transducers

- DC tachometer
  - DC generator
  - permanent magnet
  - output voltage proportional to angular velocity
  - residual ripple

- AC tachometer
  - electric machine
  - cup rotor (low inertia moment)
  - two stator windings mutually in quadrature
  - sinusoidal voltage proportional to angular velocity
  - residual ripple when rotor is still