Force-Control

$$f_e = k_e x. \tag{11.7}$$

The equation describing this physical system is

$$f = m\ddot{x} + k_e x + f_{\text{dist}}, \tag{11.8}$$

$f_e = k_e x$

$x = k_e^{-1} f_e$

or, written in terms of the variable we wish to control, f_e,

$$f = \underbrace{m k_e^{-1}}_{\alpha} \ddot{f}_e + \underbrace{f_e + f_{\text{dist}}}_{\beta}. \tag{11.9}$$

Using the partitioned-controller concept, as well as

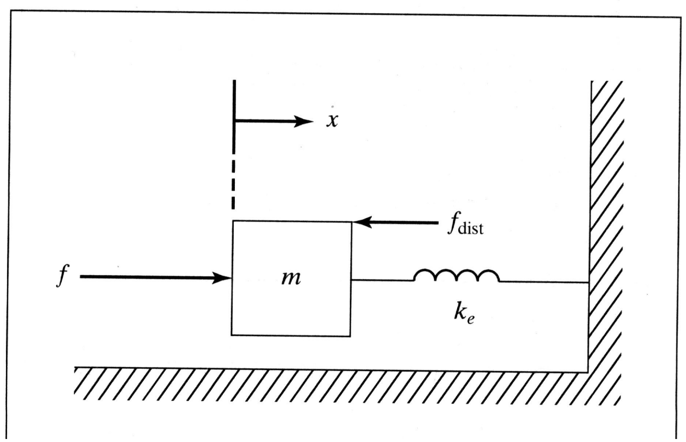
$$\alpha = m k_e^{-1}$$

and

$$\beta = f_e + f_{\text{dist}}$$

we arrive at the control law,

$$f = m k_e^{-1} \left[\ddot{f}_d + k_{vf} \dot{e}_f + k_{pf} e_f \right] + f_e + f_{\text{dist}}, \tag{11.10}$$



$$f = mk_e^{-1}\left[\ddot{f}_d + k_{vf}\dot{e}_f + k_{pf}e_f\right] + f_e + f_{\text{dist}},$$

$$\ddot{e}_f + k_{vf}\dot{e}_f + k_{pf}e_f = 0.$$

If we choose to leave the f_{dist} term out of our control law, equate (11.9) and (11.10), and do a steady-state analysis by setting all time derivatives to zero, we find that

$$e_f = \frac{f_{\text{dist}}}{\alpha}, \qquad \alpha = mk_e^{-1}k_{pf}, \tag{11.12}$$

Therefore, we suggest the control law

$$f = mk_e^{-1}\left[\ddot{f}_d + k_{vf}\dot{e}_f + k_{pf}e_f\right] + f_d.$$

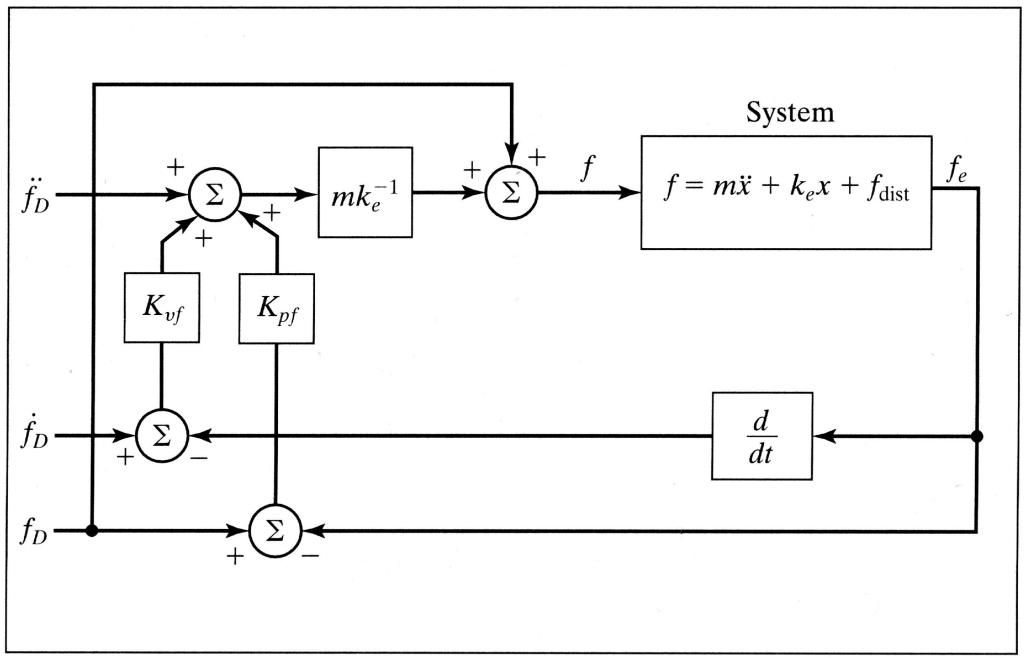
$$e_f = \frac{f_{\text{dist}}}{1+\alpha}.$$

Closed-Loop Force Control

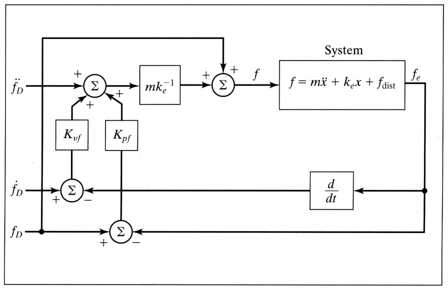
$$f = mk_e^{-1}\left[\ddot{f}_d + k_{vf}\dot{e}_f + k_{pf}e_f\right] + f_d. \qquad (11.14)$$

Figure 11.6 is a block diagram of the closed-loop system using the control law (11.14).

Generally, practical considerations change the implementation of a force-control servo quite a bit from the ideal shown in Fig. 11.6. First, force trajectories are



Practical Force-Control System



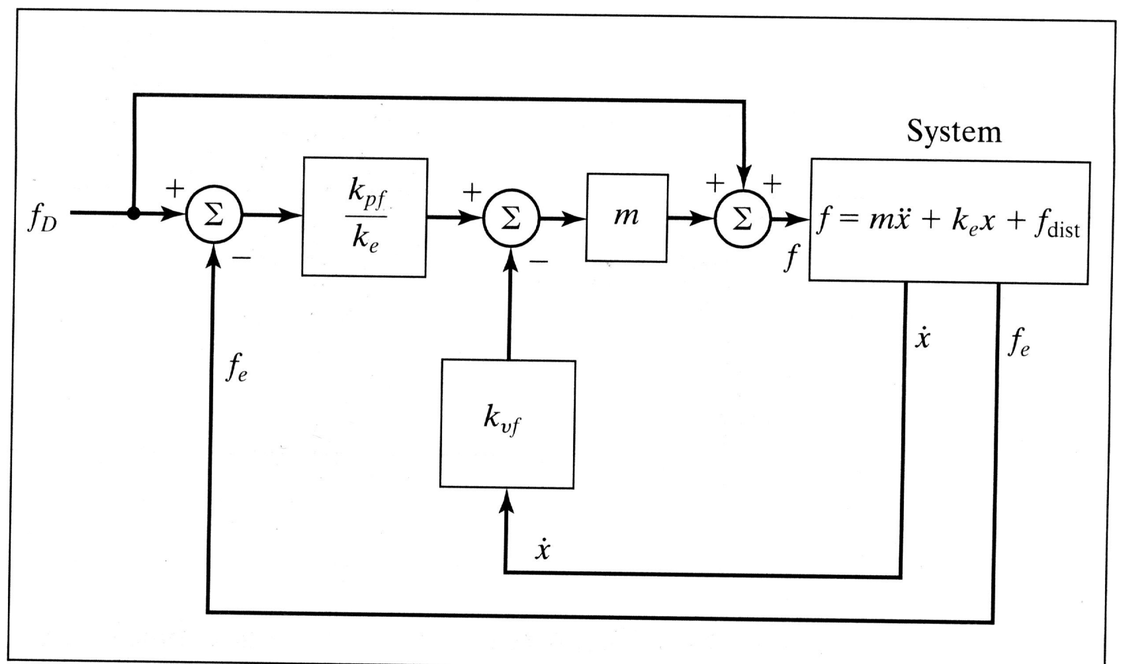


FIGURE 11.7: A practical force-control system for the spring–mass system.

Hybrid-Controller

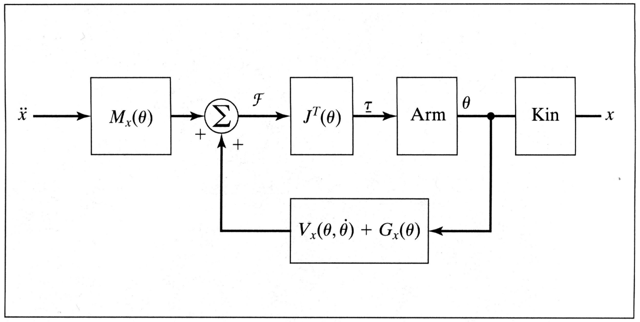


FIGURE 11.11: The Cartesian decoupling scheme introduced in Chapter 10.

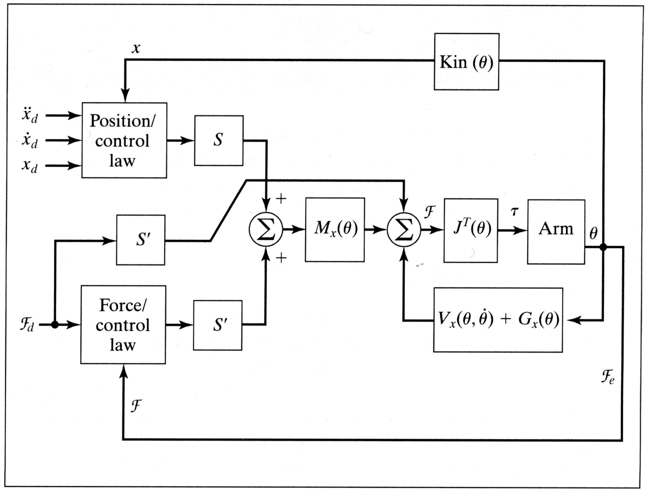


FIGURE 11.12: The hybrid position/force controller for a general manipulator. For simplicity, the velocity-feedback loop has not been shown.

Torque Control

$$\tau_m = k_m i_a.$$

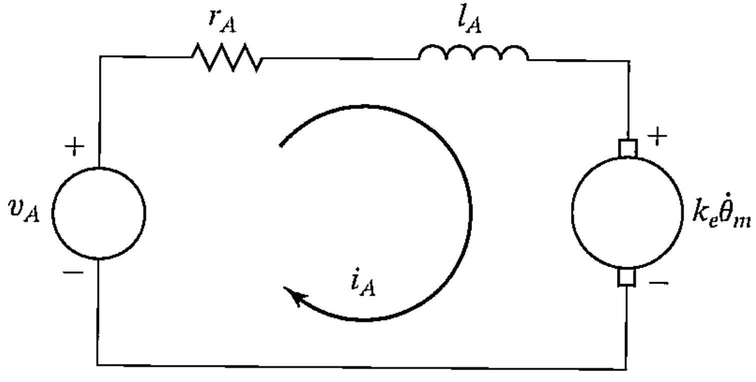
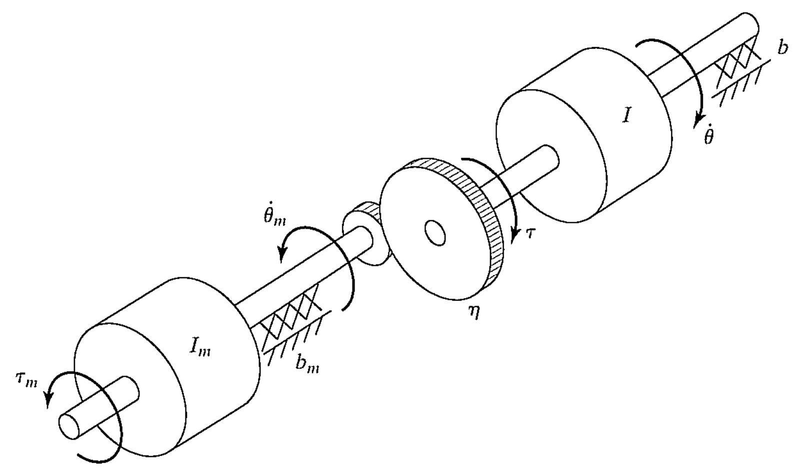


FIGURE 9.11: The armature circuit of a DC torque motor.

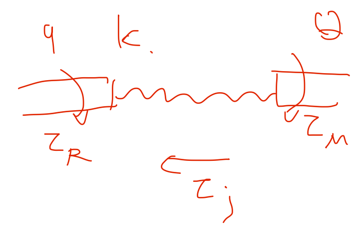
$$l_a \dot{i}_a + r_a i_a = v_a - k_e \dot{\theta}_m.$$

Effective Inertia



$$\tau = \eta \tau_m,$$

$$\dot{\theta} = (1/\eta)\dot{\theta}_m,$$



$$\tau_m = I_m \ddot{\theta}_m + b_m \dot{\theta}_m + (1/\eta)\left(I\ddot{\theta} + b\dot{\theta}\right),$$

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

$$\tau_j = k(\Theta - q)$$

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

Task Requirements

- Robots usually don’t fit the ideal of “universally programmable” devices
- Degrees of freedom should match the task
  - Minimizes cost (hardware, computing power, and power consumption)
  - Minimizes size/weight

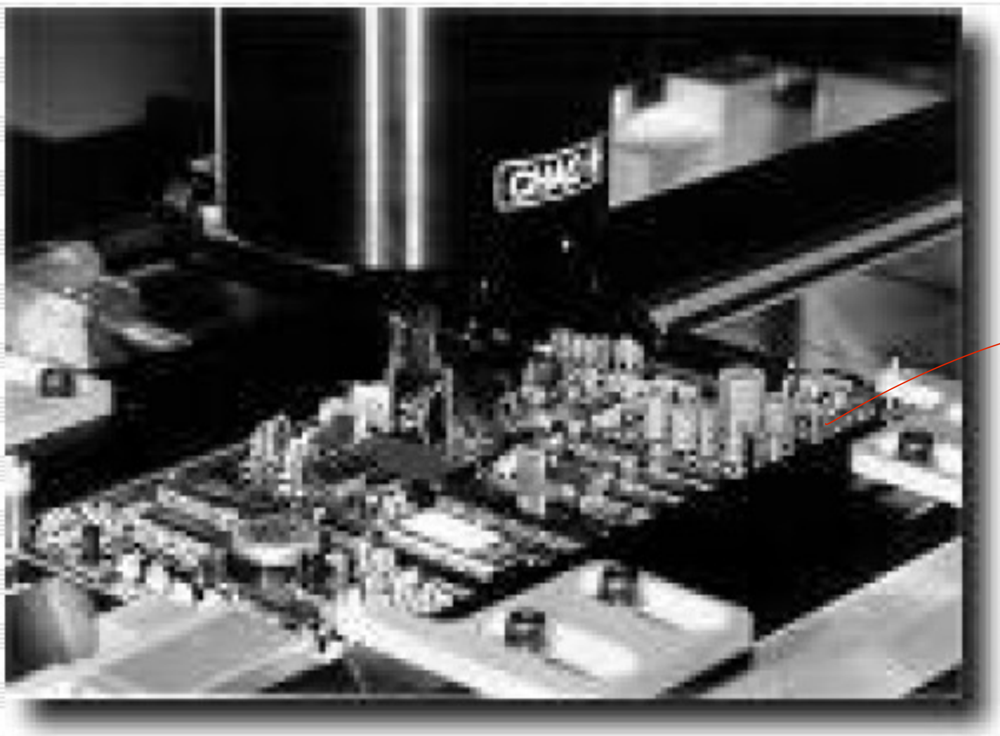
Example: Haptic Device

- 3dof actuation
- Torque not important for many virtual environments
- However, 6dof positioning is important

Sensable Technologies

Example: Circuit Assembly

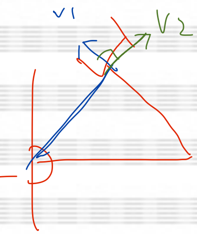
- Placement of components on a circuit board (4 dof)



Adept Technology

Ø isotropic

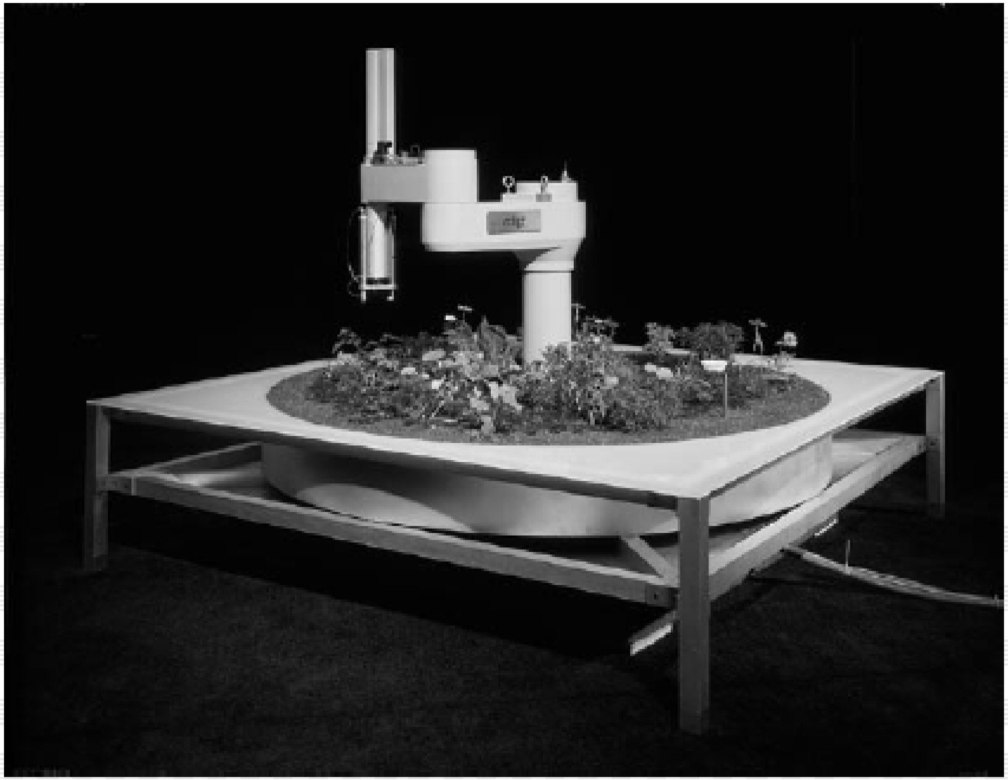
orthonormal.



Every velocity response differ more than dimension

Other Task Requirements

- Workspace
  - Scale and precise shape
- Load Capacity
  - Sizing of structural members
- Speed
- Accuracy and Precision



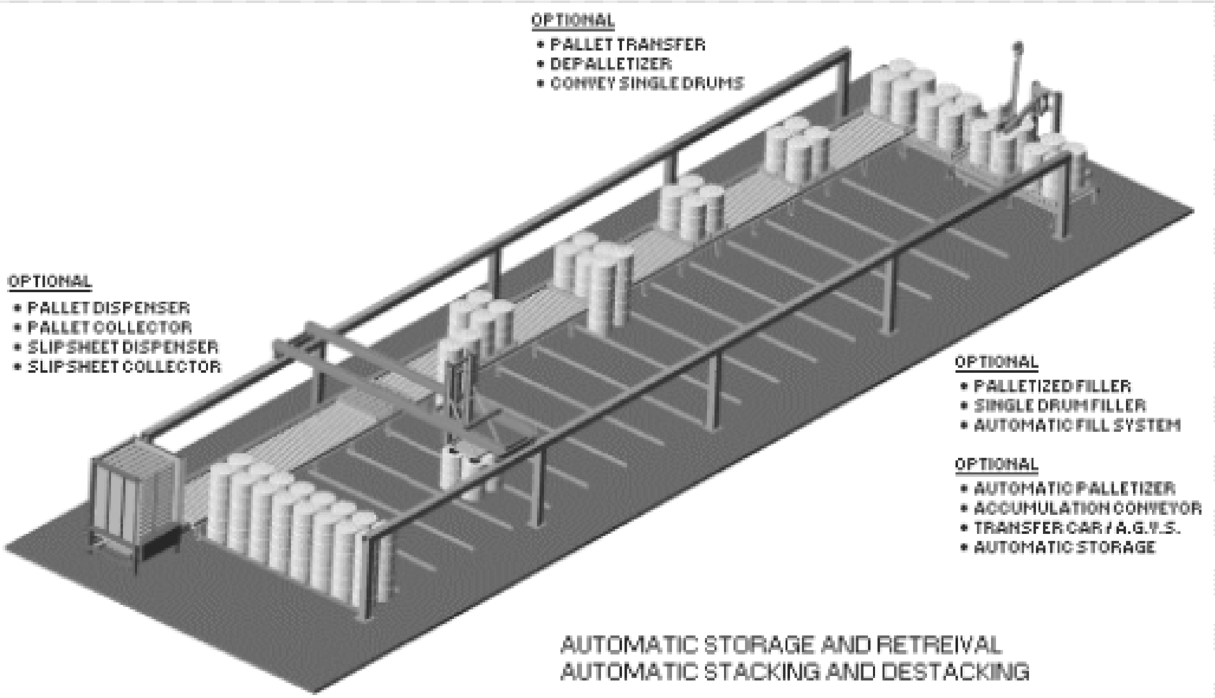
Telegarden (Goldberg, UC Berkeley)

Kinematic Configurations

- Decide degrees of freedom first
- Then choose kinematic configuration to obtain the best
  - Workspace
  - Dynamic properties
  - Use of actuators and sensors
  - Accuracy
- A general, 6dof manipulator is usually classified by the first 3 dof plus a wrist

Cartesian Manipulator

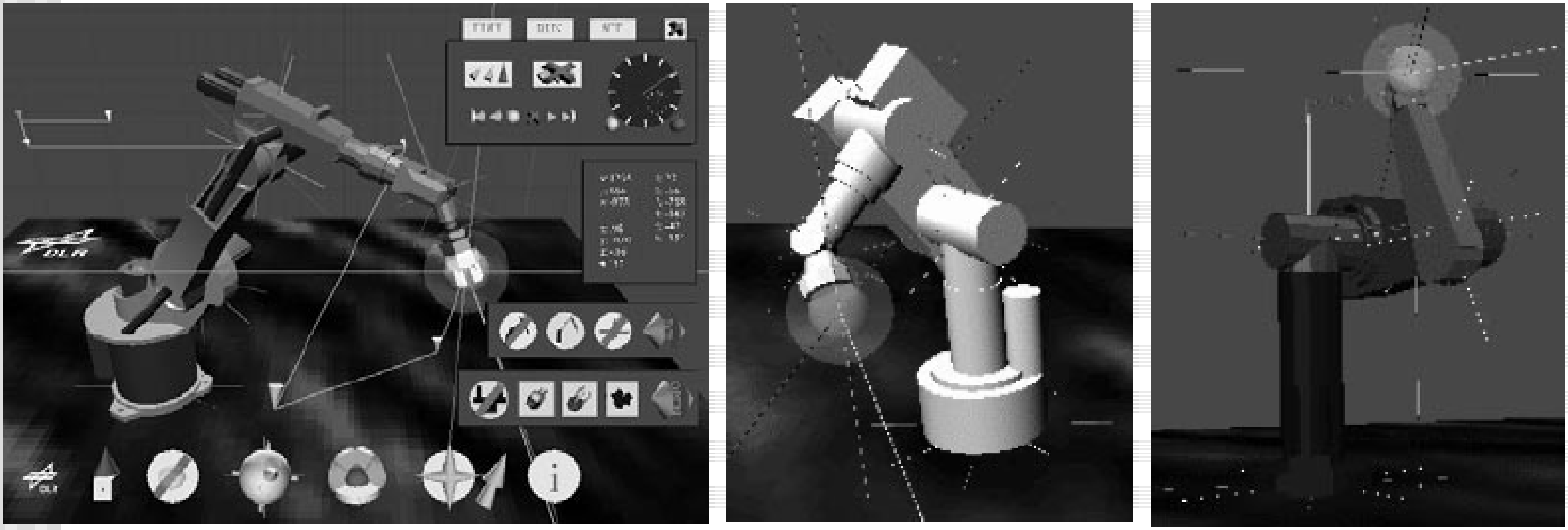
- Joints 1, 2, and 3 are prismatic
- Mutually Orthogonal
- Decoupled x, y, and z
- Often used for gantry robots



Specialty Equipment

Articulated Manipulator

- Also called jointed, elbow, or anthropomorphic manipulator
- Least intrusion into the workspace



VRML models from Gerd Hirzinger

Workspace Attributes

- Design efficiency
  - How much material is needed to build different designs with the same workspace?
  - Length sum $$L = \sum_{i=1}^{N} (a_{i-1} + d_i)$$
  - Structural length index $$Q_L = \frac{L}{\sqrt[3]{W}}$$

(*W* = workspace volume, d_i = distance between joint limits)

Condition of Workspace

- When the manipulator is near a singular point, actions of the manipulator are said to be ***poorly conditioned***.
- Singular conditions are given by

$$\det(J(\theta)) = 0$$

- Thus, use the Jacobian as a measure of manipulator dexterity

Manipulability Measure (vel)

- Yoshikawa defines manipulability as

$$w = \sqrt{\det(J(\theta)J^T(\theta))}$$

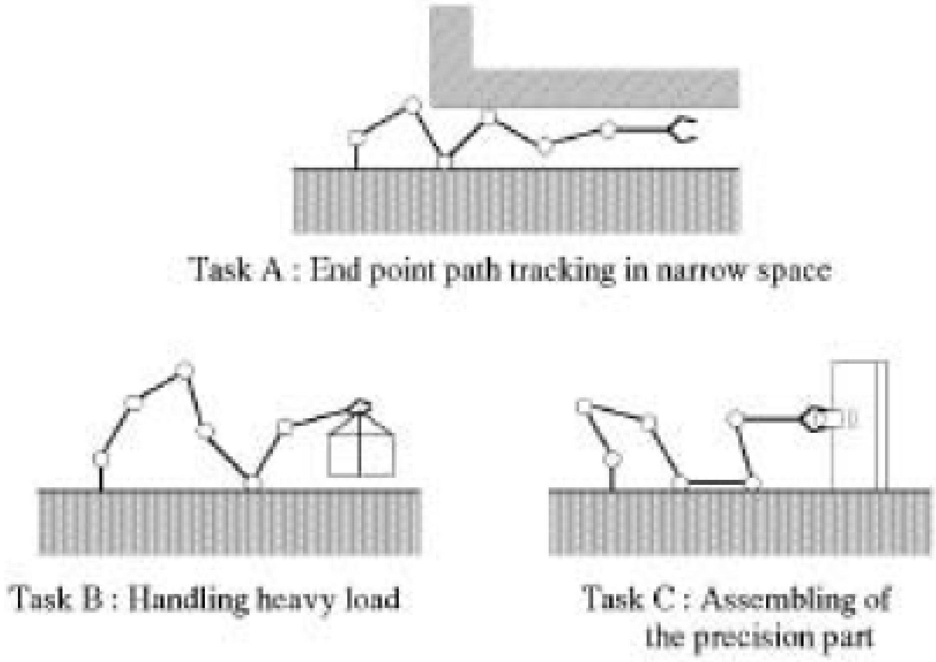
- For a nonredundant manipulator

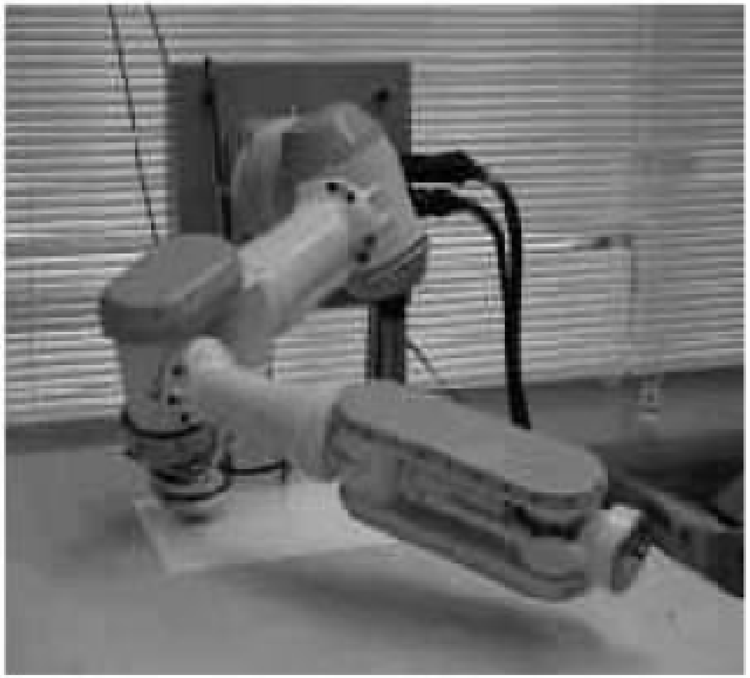
$$w = \left|\det(J(\theta))\right|$$

- A good manipulator has a high *w* over large areas of its workspace

Redundant structures

- Can be useful for avoiding collisions while operating in cluttered work environments

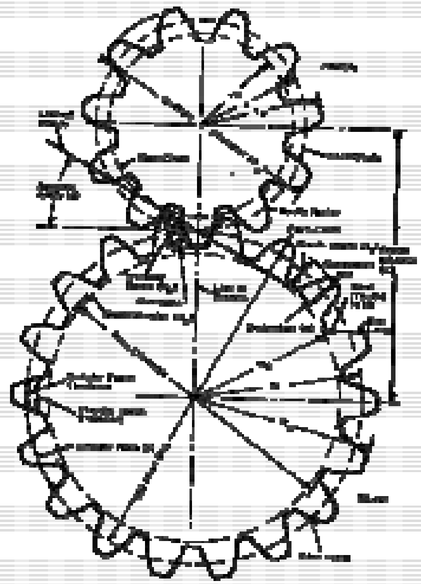




Bracing control with redundant manipulators (Fukuda Laboratory, Nagoya University)

Reduction & Transmission

- **Gears** produce large reductions in a compact configuration
  - Disadvantages: backlash and friction



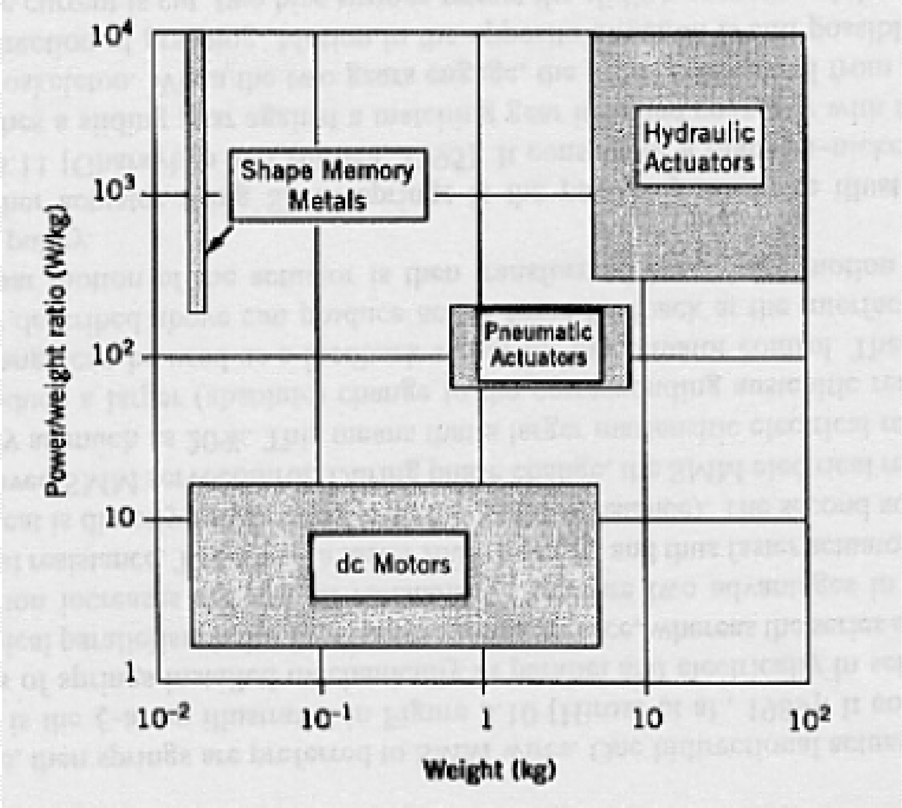
Frank Buchsbaum

- Gear ratio: relationship between input and output speeds & torques

$$\eta > 1 \qquad \dot{\theta}_o = \frac{\dot{\theta}_i}{\eta} \qquad \tau_o = \eta \tau_i$$

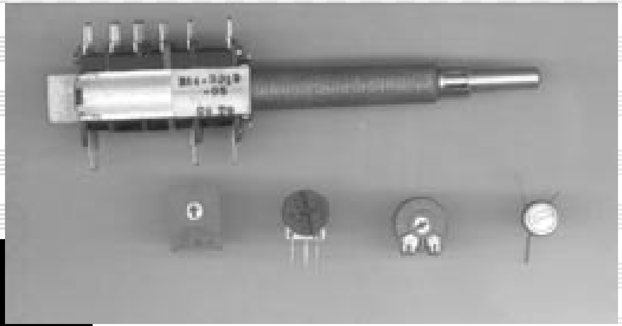
Actuator Types

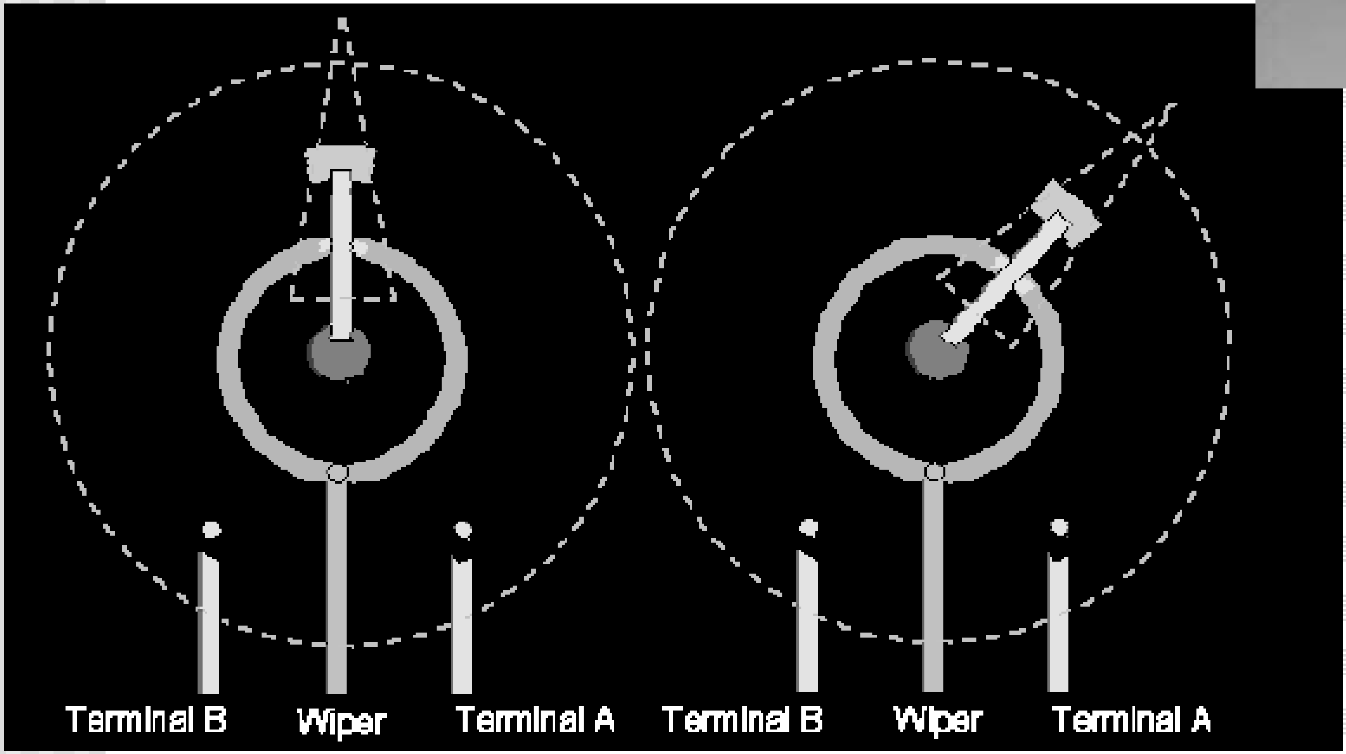
- Electric motors
  - DC (direct current)
  - Brushed
  - PM (permanent magnet)
- Pneumatic Actuators

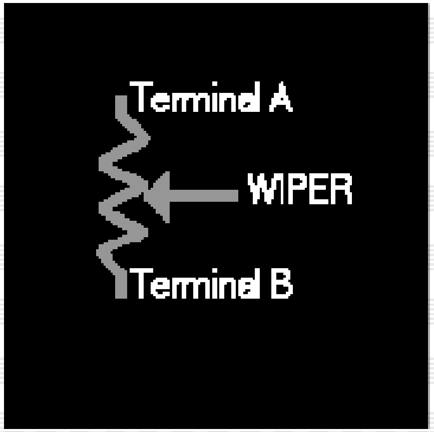


Potentiometers

- Produce a voltage proportional to shaft position
- Voltage divider





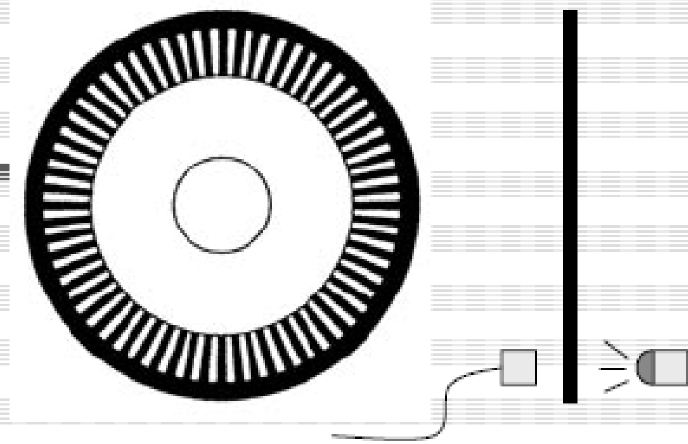


Babin Perry

Potentiometers

- Problems:
  - Friction (for backdriveable systems like haptic devices)
  - Noise
  - Resolution
  - Linearity

Optical Encoders



- How do they work?
  - A focused beam of light aimed at a matched photodetector is interrupted periodically by a coded pattern on a disk
  - Produces a number of pulses per revolution (Lots of pulses = high cost)
- Quantization problems at low speeds
- Absolute vs. referential

① * 不考编程题，例如 $\vec{V} \Rightarrow J$

② 2 张面的 chart sheet

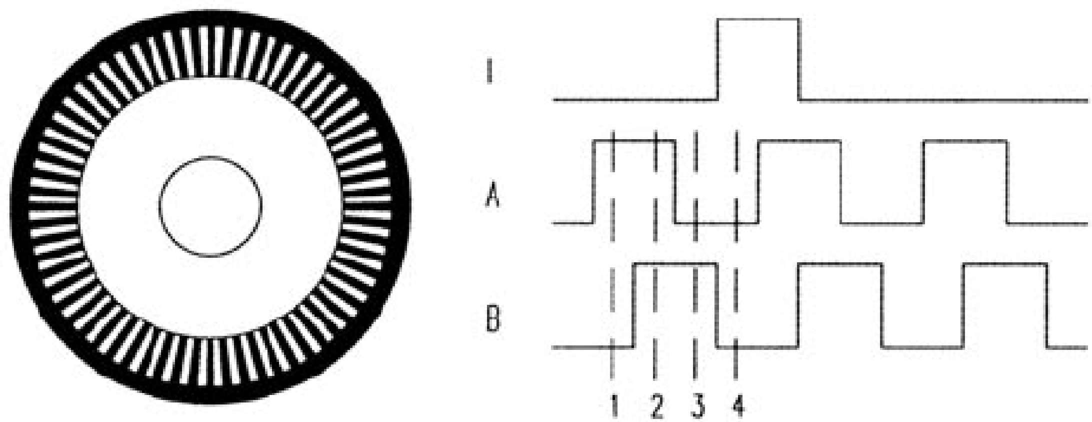
③ 可能会考 position control 的性质

④ Inverse kinematic $\Rightarrow$ how to use J

⑤ no pencil

Optical Encoders

- Phase-quadrature encoder



State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

- 2 channels, 90° out of phase
  - allows sensing of direction of rotation
  - 4-fold increase in resolution