Lecture 2

- Registration and schedule
  - TimeEdit / Canvas
- Sign-up lists matlab / RobotStudio exercises
- Student representatives (2 students)
  - NN
  - NN
- Project list will be announced 2020-09-08
  - Groups 3-4 students
- Today Chapter 2

LUND UNIVERSITY

FRTF20 Applied Robotics

What is a Robot

A robot is a **reprogrammable**, **multifunctional** manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

The word “robot” is derived from the Czech word „robota“ meaning heavy, monotonous or forced labour work. It was introduced in the play R.U.R. (Rossums Universal Robots) written by Karel Capek around 1920 with first performance in Prague 1921.

LUND UNIVERSITY

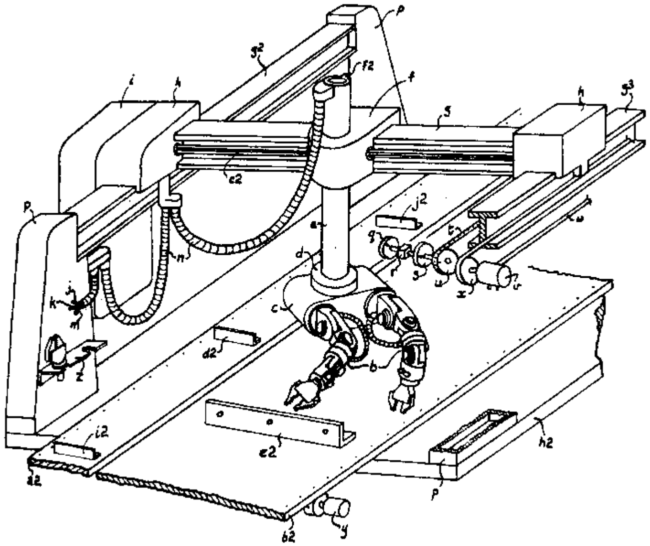
Automatons and androids – 18th century

- Automaton: a machine which by means of mechanical, pneumatic, hydraulic, or electric devices, is able to do acts imitating human or animal actions.
- Android: an automaton designed to resemble a human.

Automaton Duck by Jacques de Vaucanson in 1739.

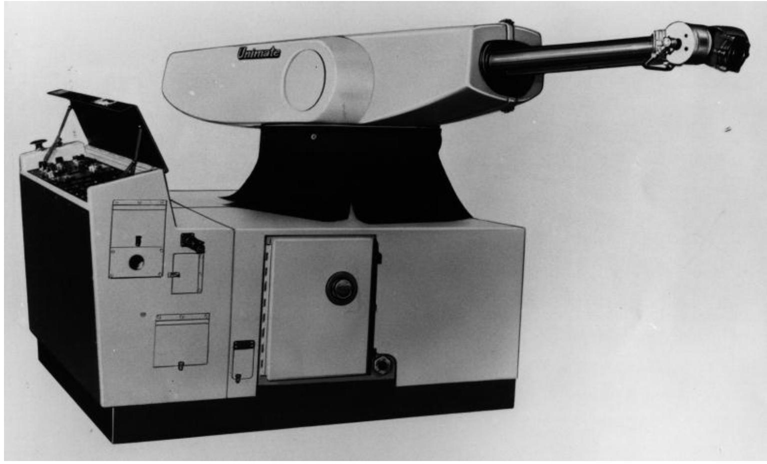
Imitation of eating, swallow of grain and digesting. Drinking, paddle and quacking, and moving the wings

The Industrial Robot



Patent of first robot by Kenwards (1957)

Unimate 2000, first generation of Industrial robot (1961).
Based on a patent by George C Devol

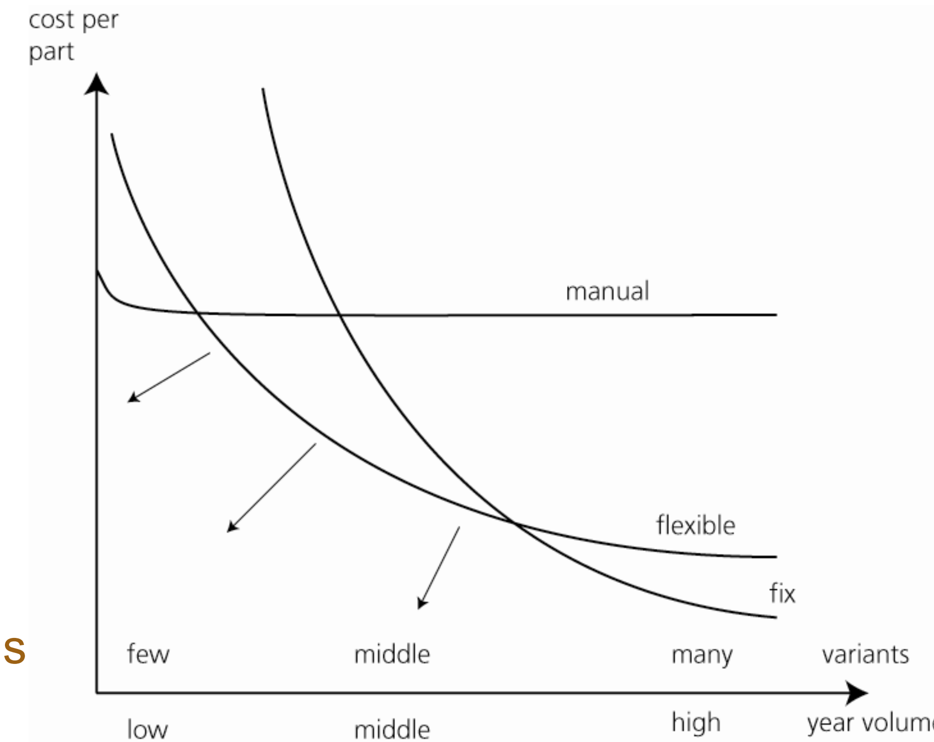


The first completely electrically driven and microprocessor controlled robot

https://www.youtube.com/watch?v=2xNgQhLAPyI

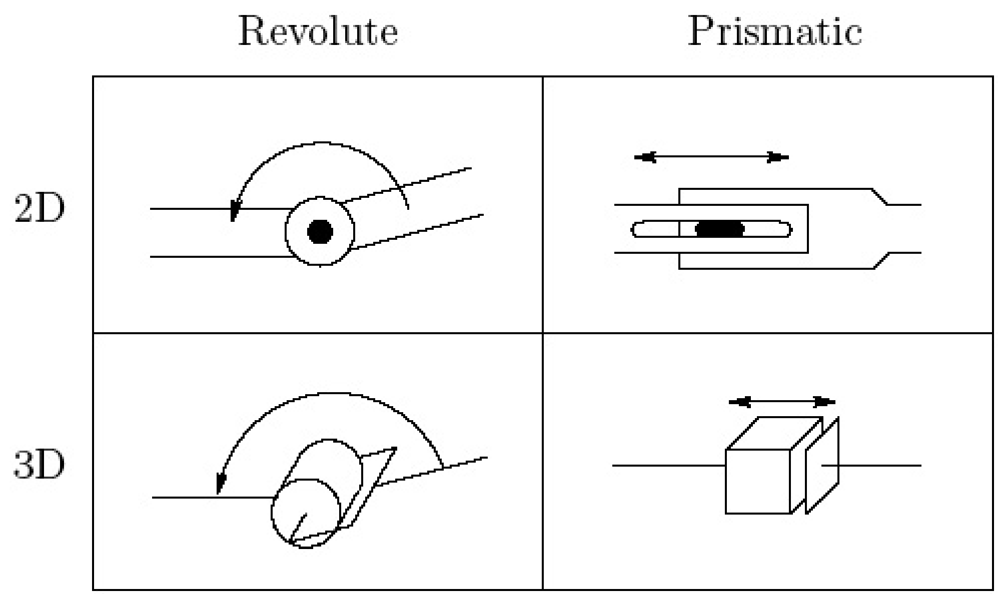
Benefits and driving forces

- Easy change of operations
- Even quality
- Less scrap
- Better work environment
- Flexible with respect to volume
- Can cope with complex operations



Mathematical Modeling of Robots

- Links and Joints



- Configuration Space

A ***configuration*** of a manipulator is a complete specification of the location of every point on the manipulator.
The set of all configurations is called the ***configuration space***.

Degrees of freedom

- An object has n degrees of freedom (DOF) if its configuration can be minimally specified by n parameters.
- The number of DOF is equal to the dimension of the configuration space.
- For a robot manipulator:
  number of joints = number of DOF

Articulated Manipulator: ABB Irb1400

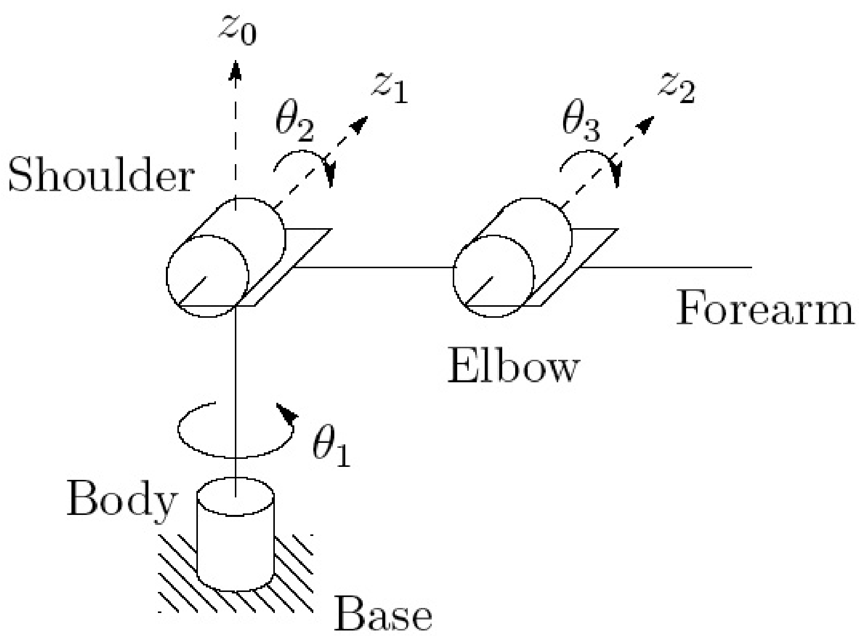


Figure 1.9: The ABB IRB1400 Robot, a six-DOF elbow manipulator (right). The symbolic representation of this manipulator (left) shows why it is referred to as an anthropomorphic robot. The links and joints are analogous to human joints and limbs. (Photo courtesy of ABB.)

SCARA Manipulator: Adept Cobra Smart600

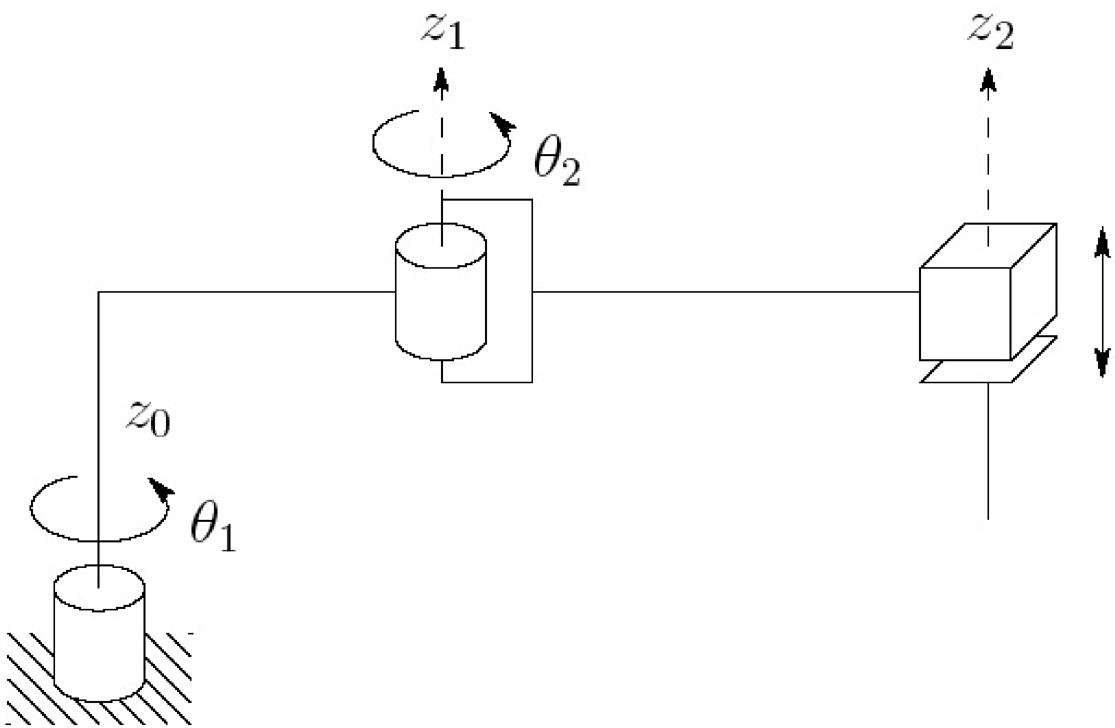
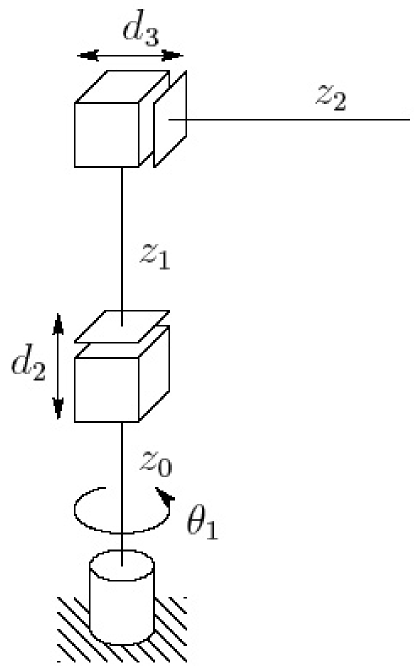


Figure 1.13: Symbolic representation of the SCARA arm.

Cylindrical robot: Seiko RT3300



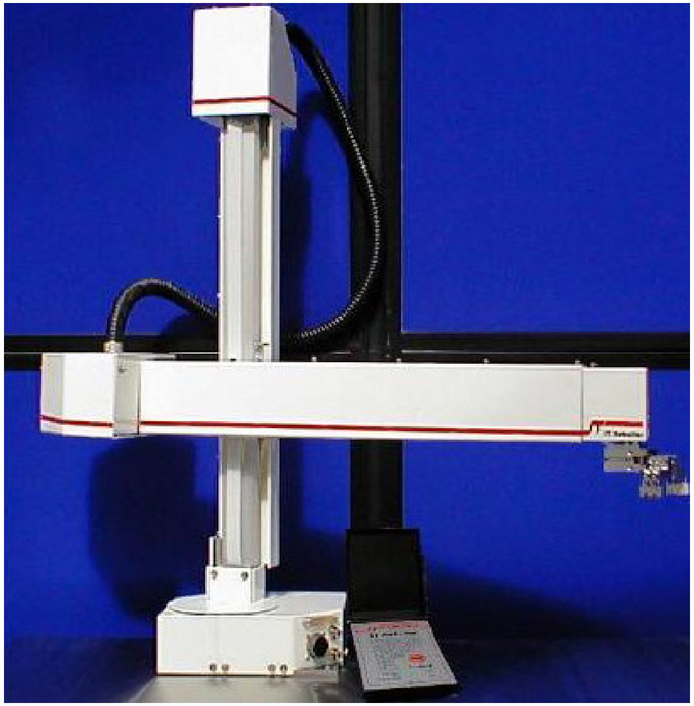
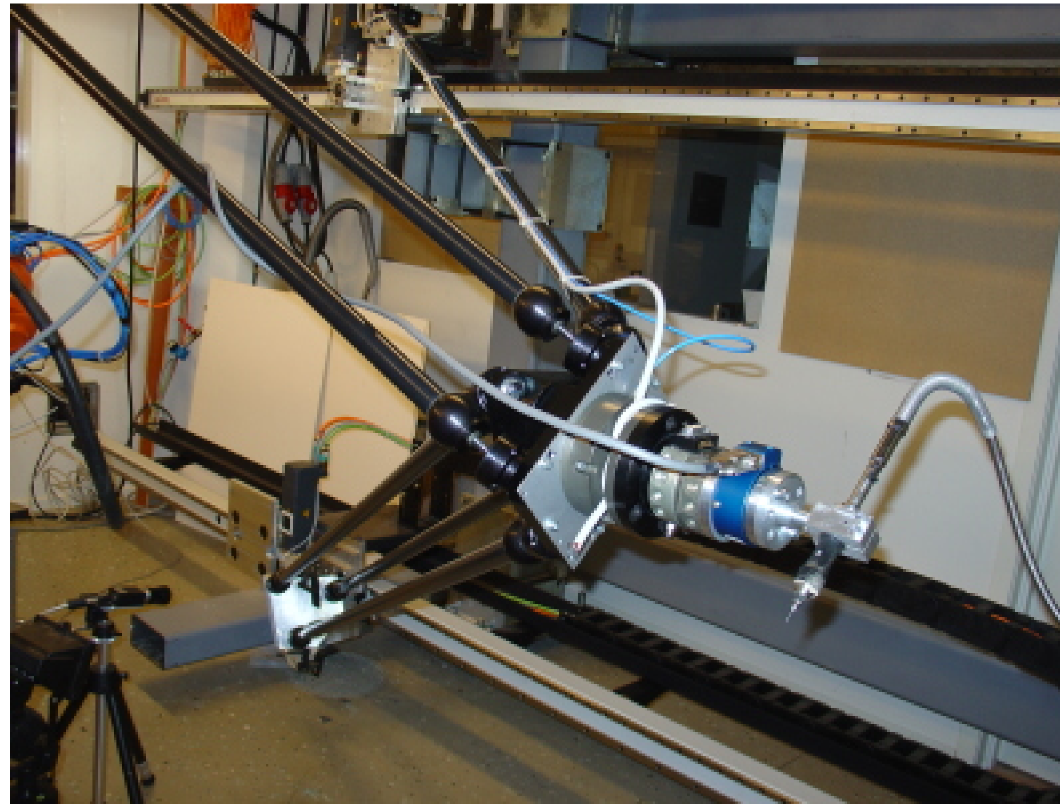


Figure 1.15: The Seiko RT3300 Robot cylindrical robot. Cylindrical robots are often used in materials transfer tasks. (Photo courtesy of Epson Robots.)

Gantry-Tau (linear actuators for PKM)



https://www.youtube.com/watch?v=HKe1FXP_ajg

LUND UNIVERSITY

Robot task example

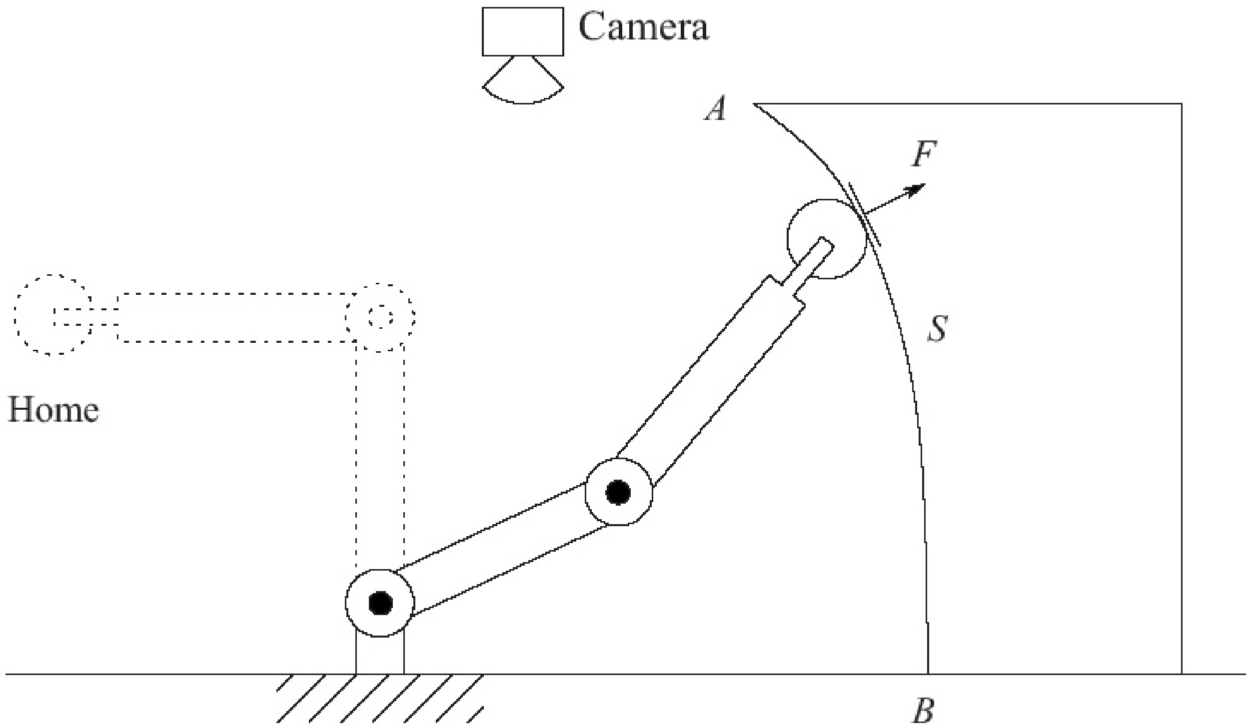
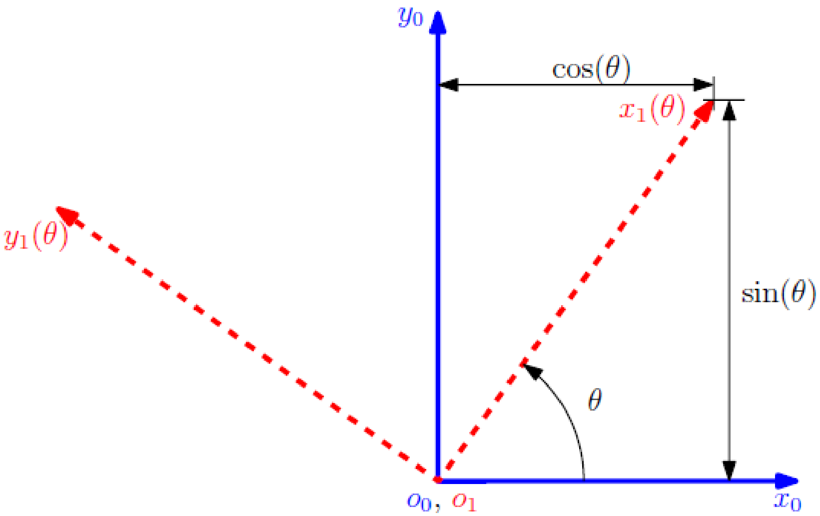
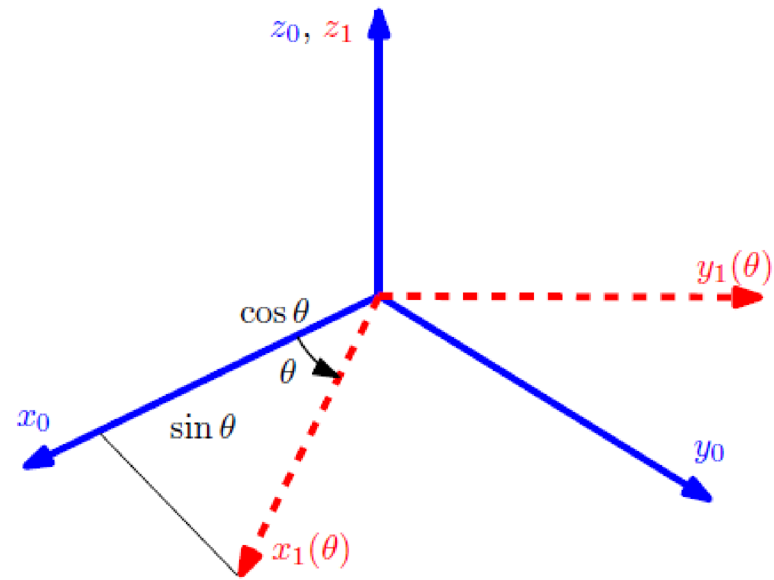


Figure 1.19: Two-link planar robot example. Each chapter of the text discusses a fundamental concept applicable to the task shown.

Rotations and translations in 2D/3D

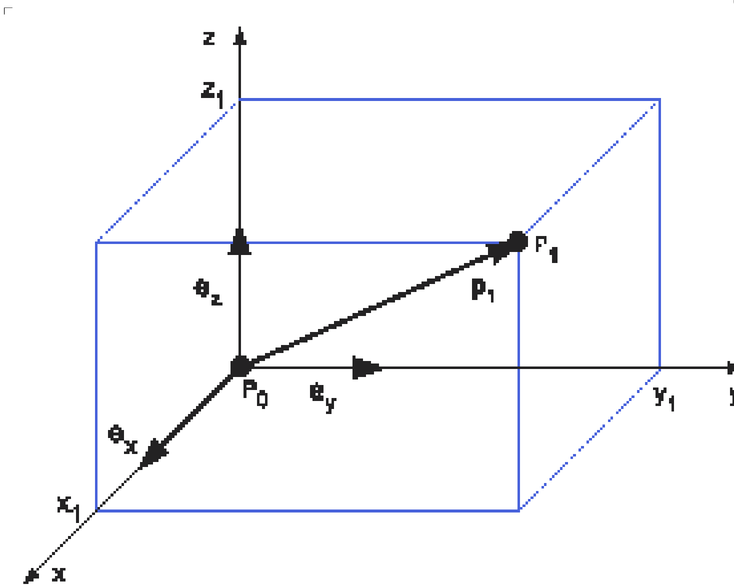


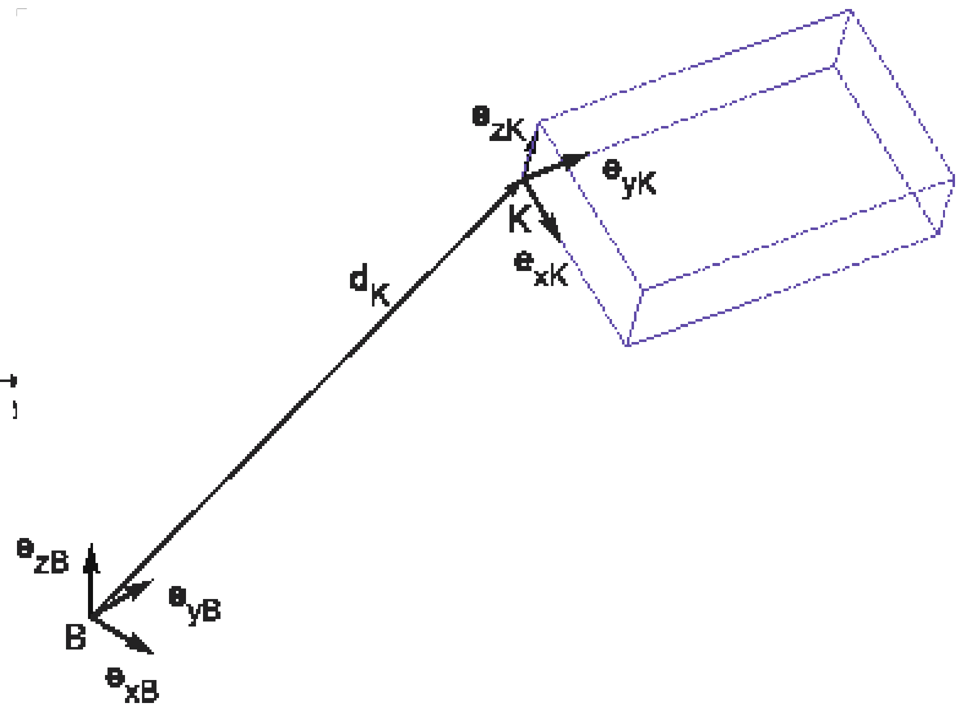


$$R_1^0(\theta) = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}$$

$$R_1^0(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \{=: R_{z,\theta}\}$$

Representing Positions & Orientations





$$ {}^B\boldsymbol{R}_K = \left({}^B\boldsymbol{e}_{xK} \quad {}^B\boldsymbol{e}_{yK} \quad {}^B\boldsymbol{e}_{zK} \right) = \begin{pmatrix} u_x & v_x & w_x \\ u_y & v_y & w_y \\ u_z & v_z & w_z \end{pmatrix} $$

LUND UNIVERSITY

Forward kinematics

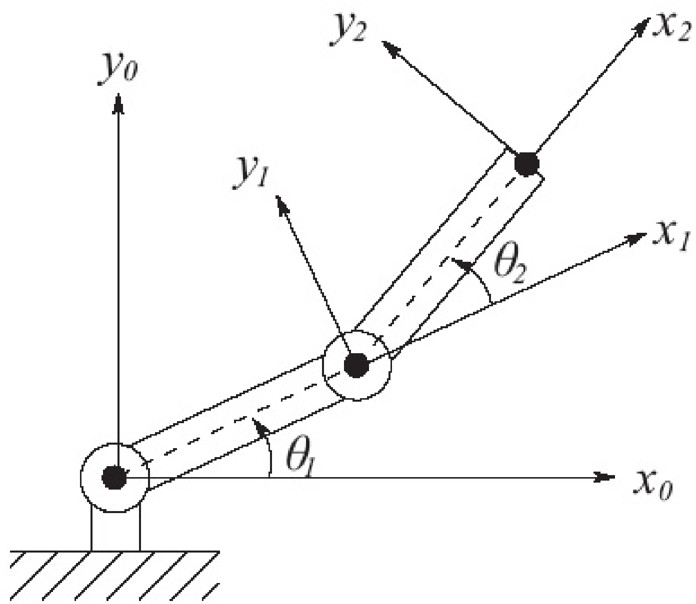


Figure 1.20: Coordinate frames attached to the links of a two-link planar robot. Each coordinate frame moves as the corresponding link moves. The mathematical description of the robot motion is thus reduced to a mathematical description of moving coordinate frames.

Inverse kinematics

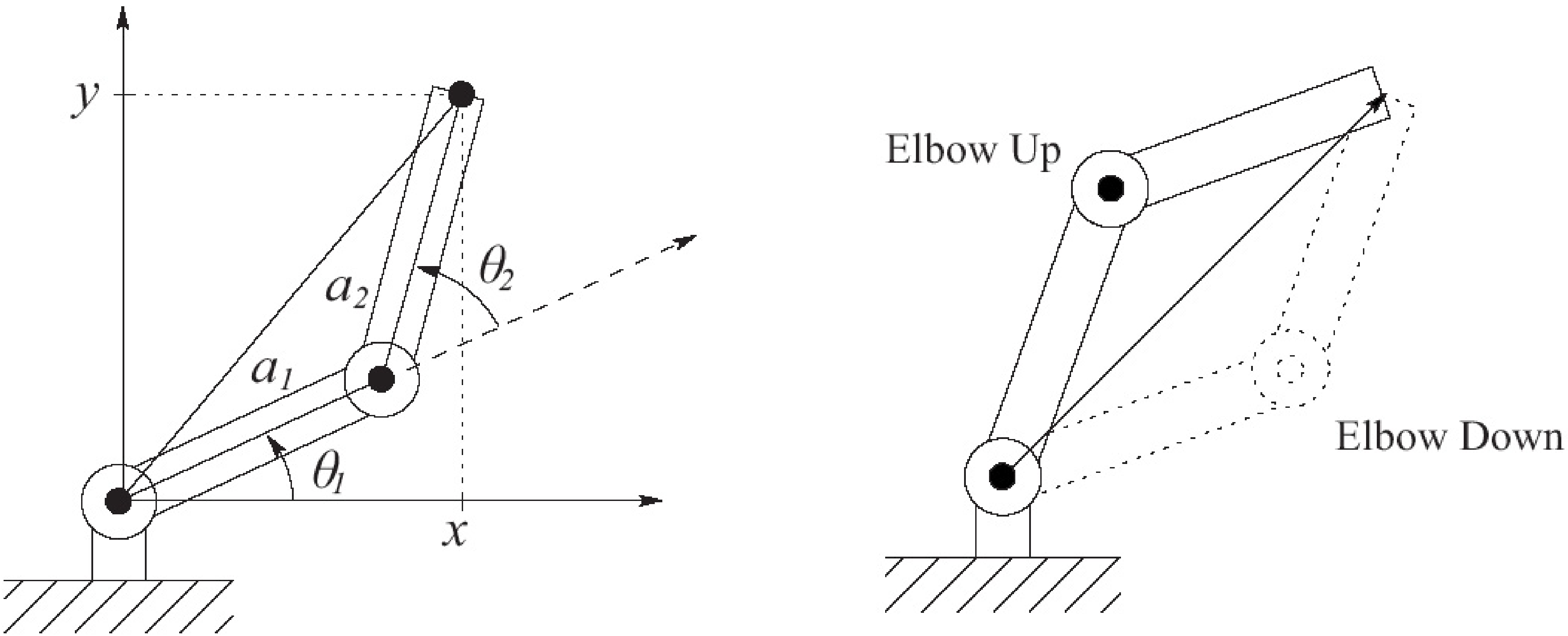
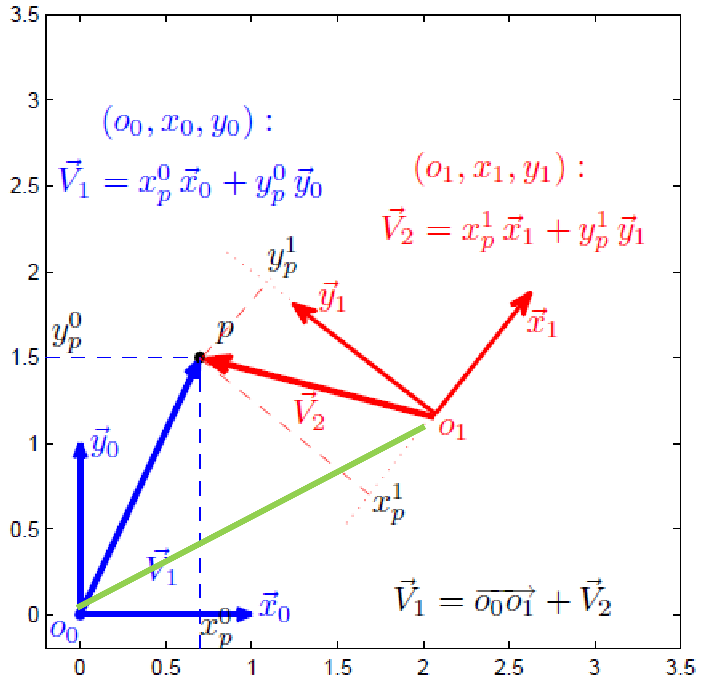


Figure 1.21: The two-link elbow robot has two solutions to the inverse kinematics except at singular configurations, the elbow up solution and the elbow down solution.

Homogenous Transformation

Combine both rotation and translation in one matrix



$$\underbrace{\begin{bmatrix} p^0 \\ 1 \end{bmatrix}}_{P^0} = \boxed{\begin{bmatrix} x_p^0 \\ y_p^0 \\ z_p^0 \\ 1 \end{bmatrix} = \begin{bmatrix} (x_1^0)_x & (y_1^0)_x & (z_1^0)_x & (o_1^0)_x \\ (x_1^0)_y & (y_1^0)_y & (z_1^0)_y & (o_1^0)_y \\ (x_1^0)_z & (y_1^0)_z & (z_1^0)_z & (o_1^0)_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_p^1 \\ y_p^1 \\ z_p^1 \\ 1 \end{bmatrix}} = \underbrace{\begin{bmatrix} R_1^0 & o_1^0 \\ 0_{1\times 3} & 1 \end{bmatrix}}_{H_1^0} \underbrace{\begin{bmatrix} p^1 \\ 1 \end{bmatrix}}_{P^1}$$

Homogeneous Transformations

A 4x4 Matrix that describes “3-Space” with information that relates Orientation and Position (pose) of a remote space to a local space

This 3x3 ‘Sub-Matrix’ is the information that relates orientation of Frame_{rem} to Frame_{Local}

(This is called R the rotational Submatrix)

$$\begin{matrix} n_x & o_x & a_x & d_x \\ n_y & o_y & a_y & d_y \\ n_z & o_z & a_z & d_z \\ 0 & 0 & 0 & 1 \end{matrix}$$

D vector is the position of the <u>origin</u> of the remote space in Local Coordinate dimensions

N vector projects the X_{rem} Axis to the Local Coordinate System

O vector projects the Y_{rem} Axis to the Local Coordinate System

A vector projects the Z_{rem} Axis to the Local Coordinate System

Inverse Homogeneous Transformation

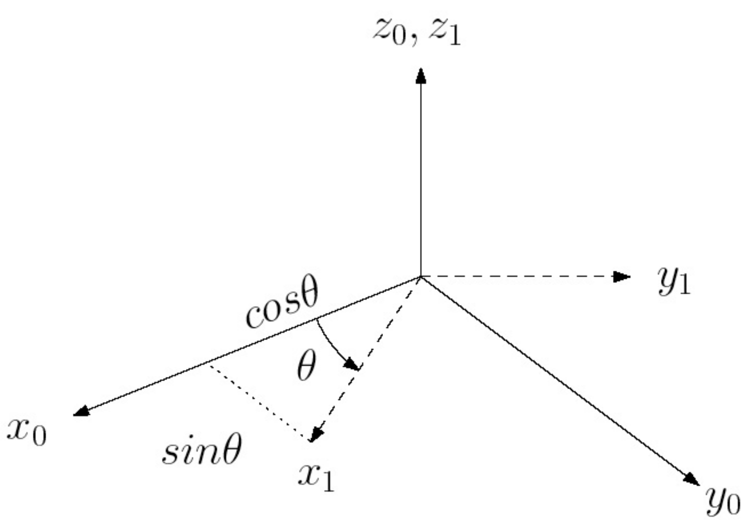
Changing our ”point of view”:

Going in the “other direction”
=> Inverse of transformation matrix

$$\begin{bmatrix} \boxed{\begin{matrix} n_x & n_y & n_z \\ o_x & o_y & o_z \\ a_x & a_y & a_z \end{matrix}} & \begin{matrix} -\left(\vec{n} \bullet \vec{d}\right) \\ -\left(\vec{o} \bullet \vec{d}\right) \\ -\left(\vec{a} \bullet \vec{d}\right) \end{matrix} \\ \begin{matrix} 0 & 0 & 0 \end{matrix} & 1 \end{bmatrix}$$

This is the Transpose of the R sub-matrix of the original HTM

Rotations about the primary axes



LUND UNIVERSITY

Rotations about current axes

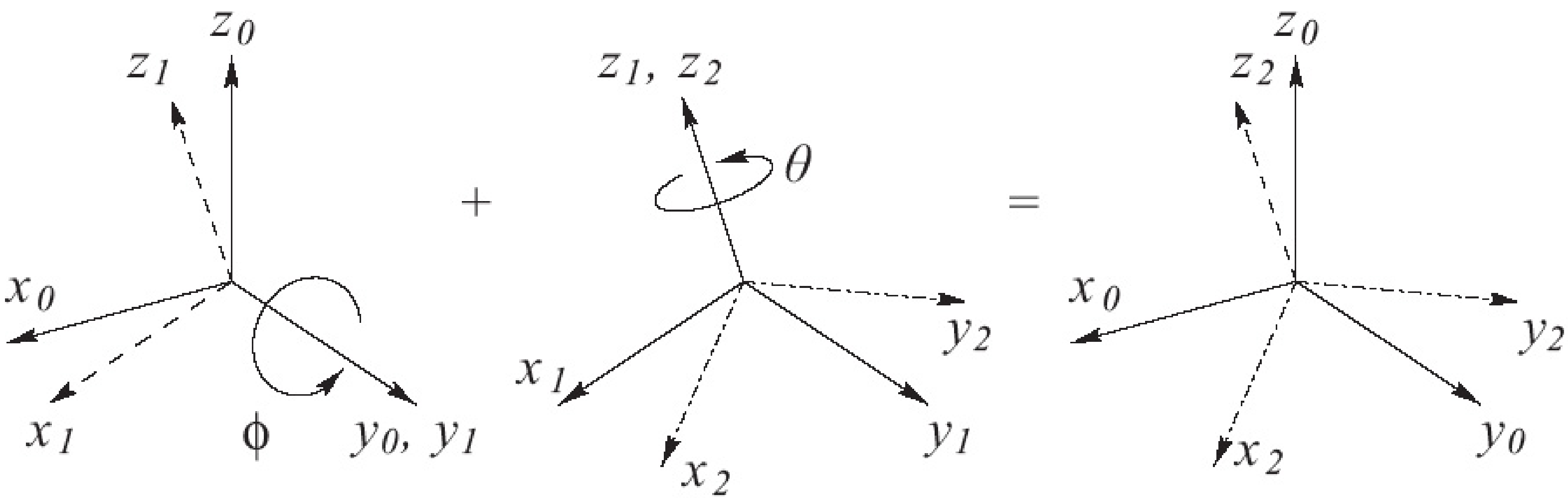
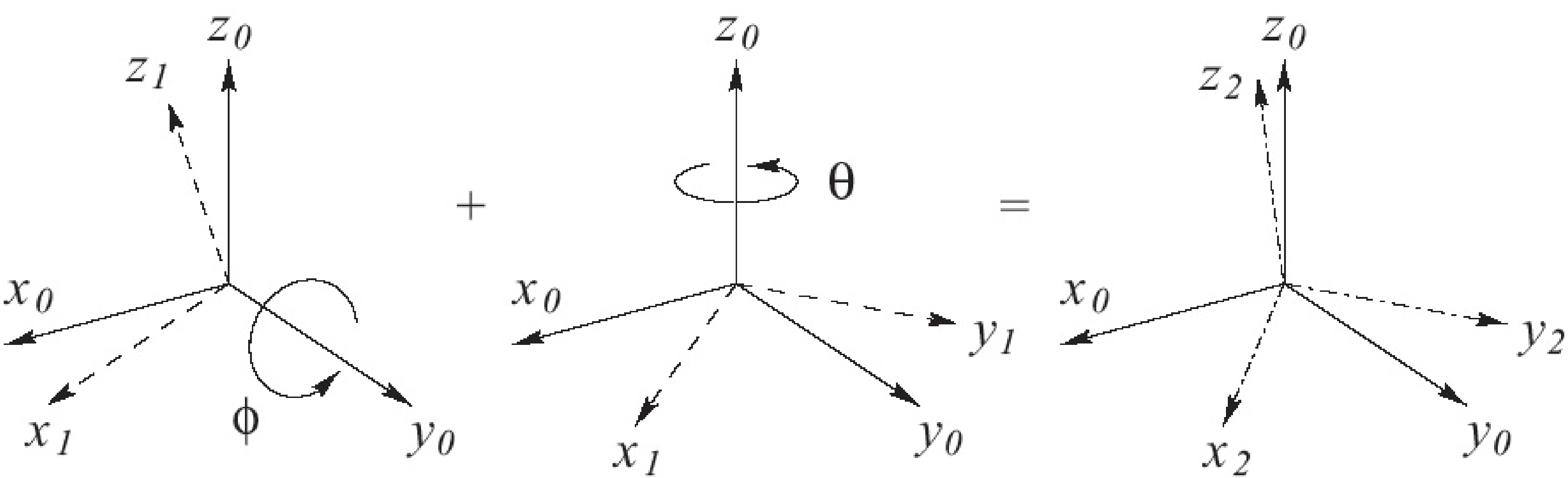
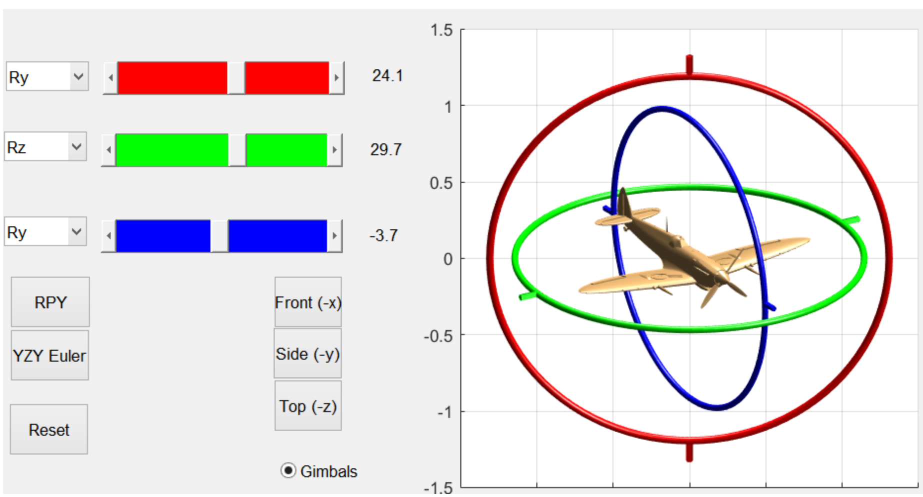
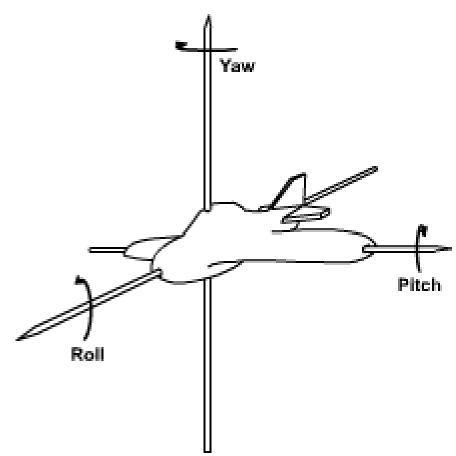


Figure 2.8: Composition of rotations about current axes.

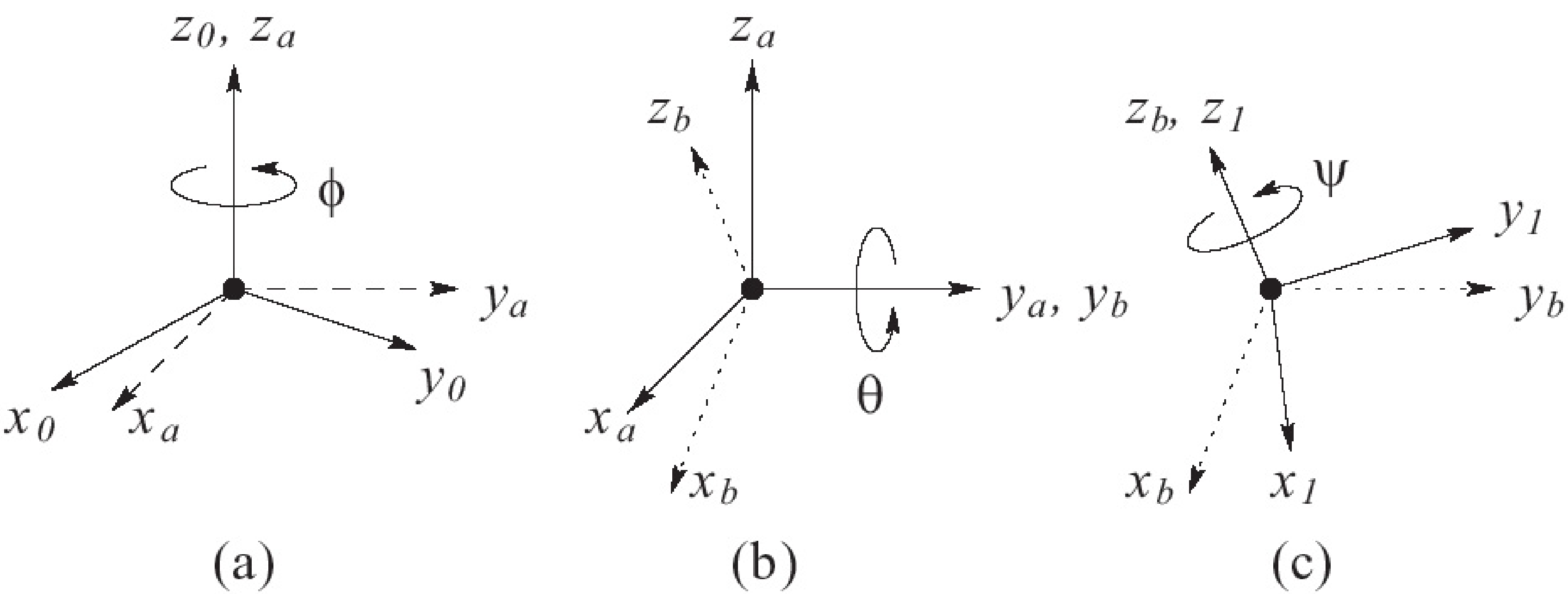
Rotations with Respect to the Fixed Frame







Euler Angles (z_0 y_a z_b)



Euler Angles continued

$$R_{zyz}(\varphi\theta\psi) = R_z(\varphi)R_y(\theta)R_z(\psi)$$

$$R_{zyz}(\varphi\theta\psi) = \begin{bmatrix} c\varphi & -s\varphi & 0 \\ s\varphi & c\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix}\begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} c\varphi c\theta c\psi - s\varphi s\psi & -c\varphi c\theta s\psi - s\varphi c\psi & c\varphi s\theta \\ s\varphi c\theta c\psi + c\varphi s\psi & -s\varphi c\theta s\psi + c\varphi c\psi & s\varphi s\theta \\ -s\theta c\psi & s\theta s\psi & c\theta \end{bmatrix}$$

Exercise

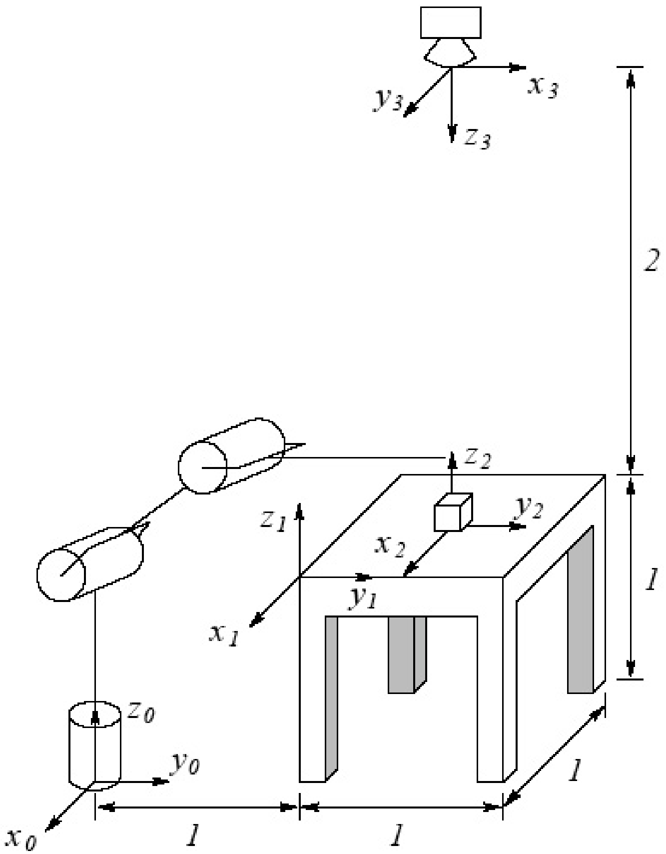


Figure 2.14: Diagram for Problem 2-39.

A cube measuring 200mm on a side is placed in the center of the table.
(Frame 2 should be in the center of the cube, i.e., slightly above the table).
A camera is situated directly above the center of the cube.

1. Find the homogeneous transformations relating Frames 1, 2 and 3 to the base frame 0.

2. Find the homogeneous transformations relating Frame 3 to Frame 2.

Solution

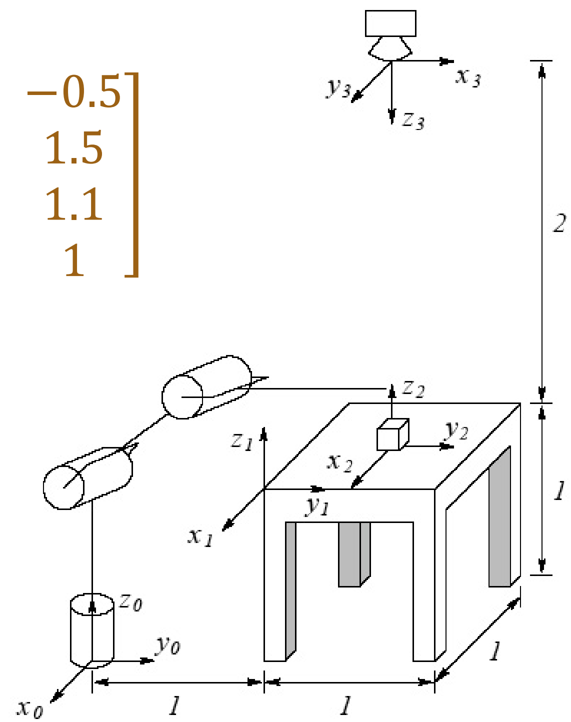
$$H_1^0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_2^0 = \begin{bmatrix} 1 & 0 & 0 & -.5 \\ 0 & 1 & 0 & 1.5 \\ 0 & 0 & 1 & 1.1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_3^0 = \begin{bmatrix} 0 & 1 & 0 & -.5 \\ 1 & 0 & 0 & 1.5 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

?

$$H_2^0 = H_1^0 H_2^1$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & 1 & 0 & 0.5 \\ 0 & 0 & 1 & 0.1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & 1 & 0 & 1.5 \\ 0 & 0 & 1 & 1.1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H_3^2 = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1.9 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_2^3 = ?$$



Composing Transformations

Rules for Composition of Rotational Transformations

- Rotation about current axes : Postmultiply
- Rotation relative to the fixed frame : Premultiply

LUND UNIVERSITY

Quaternions

Any rotation in three dimensions can be represented as a combination of an axis vector and an angle of rotation. Quaternions give a simple way to encode this axis-angle representation in four numbers and apply the corresponding rotation to a position vector representing a point relative to the origin in R^3.

Describing rotations with quaternions

Let (w, x, y, z), be the coordinates of a rotation by α around the axis defined by a unit vector. A quaternion is defined by:

$$q = w + x\mathbf{i} + y\mathbf{j} + z\mathbf{k} = w + (x, y, z) = \cos(\alpha / 2) + \vec{u}\sin(a / 2)$$

LUND UNIVERSITY

Annual walk on ”Broomsday” (16 October)

Here as he walked by
on the 16th of October 1843
Sir William Rowan Hamilton
in a flash of genius discovered
the fundamental formula for
quaternion multiplication
$i^2 = j^2 = k^2 = ijk = -1$
& cut it on a stone of this bridge.

[Source: https://en.wikipedia.org/wiki/Broom_Bridge]

Forward Kinematics

Find the position and orientation of the end effector given the values for the joint variables