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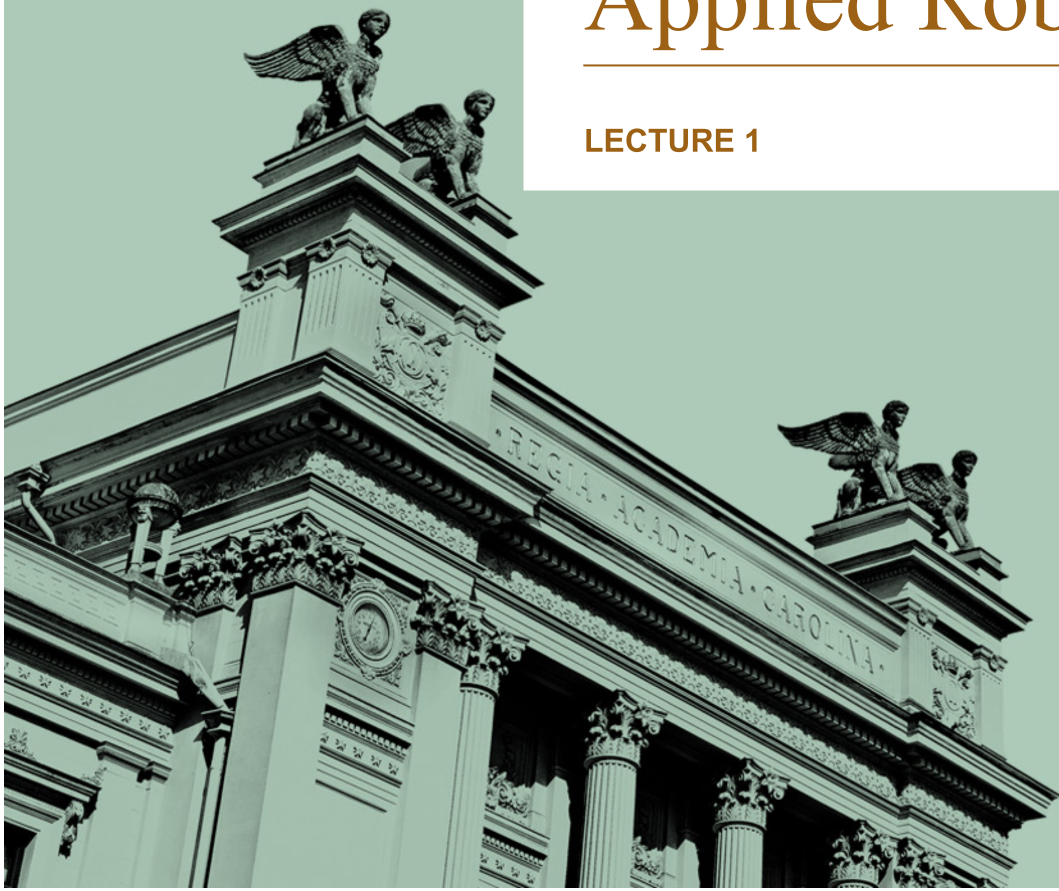
Welcome to Applied Robotics (FRTF20)

LECTURE 1

ANDERS ROBERTSSON



Applied robotics FRTF20

Lectures and course coordinator

Anders Robertsson,

Dept of Automatic Control, KC4-building (3rd floor)

http://www.control.lth.se/staff/Anders-Robertsson/

Course Administrator

Mika Nishimura,
Dept of Automatic Control, KC4-building (3rd floor)

http://www.control.lth.se/staff/Mika-Nishimura/

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Teaching assistants

Exercises/Lab exercises/Projects

Julian Salt

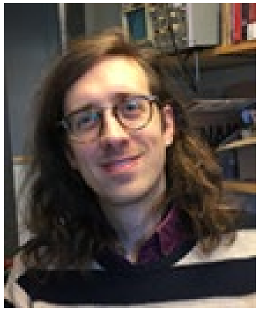
http://www.control.lth.se/staff/Julian-Salt/

Maike Klöcker

https://www.cs.lth.se/personal

Johannes Ekdahl du Rietz

http://www.product.lth.se/staff/johannes-ekdahl-du-rietz/



Greg Austin

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Course program (see www.control.lth.se and Canvas)

About | Education | Research | Staff | Contact | Publications

Search lth.se SEARCH

Control > Education > Engineering Program > FRTF20 - Applied Robotics

Engineering Program

- Specializations
- FRTF01 - Physiological Models and Computation
- FRTF05 - Automatic Control, Basic Course for DE
- FRTF05 - Automatic Control, Basic Course for CMN
- FRTF05 - Automatic Control, Basic Course for FIPi
- FRTF05 - Automatic Control, Basic Course (China)
- FRTF10/FRTN25 - Systems Engineering/Process Control
- FRTF15 - Control Theory
- FRTF20 - Applied Robotics
- FRTN01 - Real Time Systems
- FRTN05 - Nonlinear Control and Servo Systems

FRTF20 - Applied Robotics

Tillämpad robotteknik, 7.5 hp

Syllabus | CEQ | Schedule 2019

General Information

Elective for: D4-mai, E4, F4, I4, M4-me, M4-prr, MD4, Pi4, MPRR2
The course will be given in English

Aim

The purpose of the course is to give basic knowledge in industrial robotics where theory is applied on industrial applied problems. The purpose is to provide an understanding on how theory within the subject of the course can be applied in a practical way from an engineering point of view to create models for analysis, simulation and programming, and create solutions on problems which focus on efficient use of robots in industry.

Learning outcomes

Theory and Practice

- Time and venues: see Canvas/TimeEdit

  (**need to register**, log on with your STIL-account)

- Lectures (online/pre-recorded/flipped classroom)
- Exercises (kinematics,dynamics / matlab)
- Lab-exercises 1-3 (RobotStudio)
  - Hands-on exercises in RobotLab
- Hand-ins kinematics/dynamics
- Project work; report + demo

  } pass/ grade 3

- **Optional** servo-lab
- **Optional** take-home exam for higher grade (4-5)

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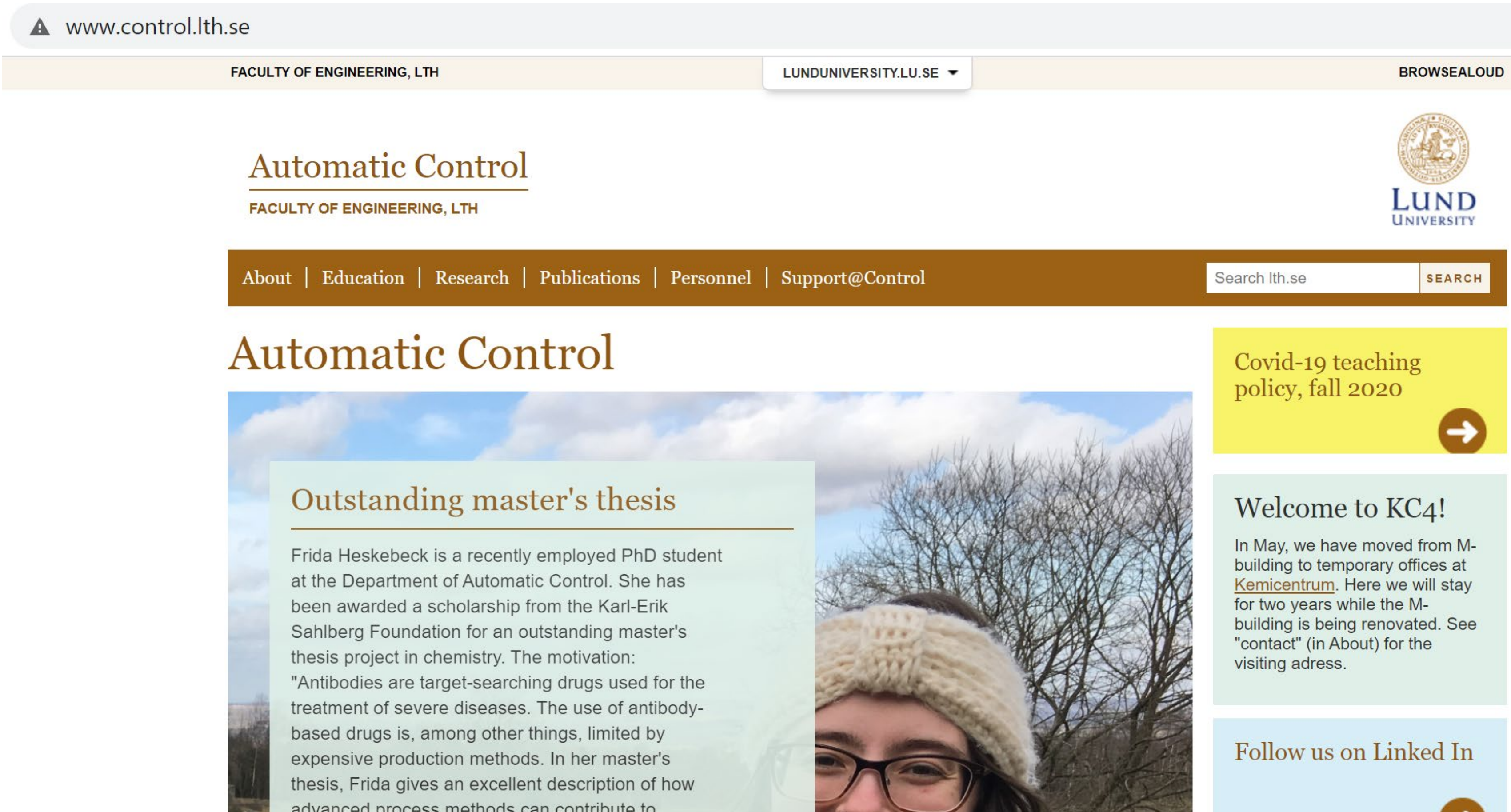
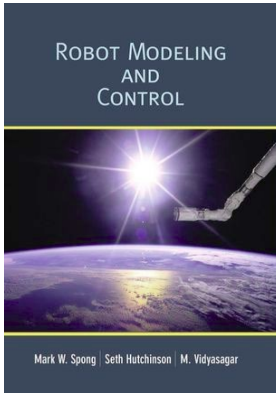
Practical issues

- Read the Covid-teaching policy at

http://www.control.lth.se/education/covid-19-teaching-policy-at-automatic-control-fall-2020/



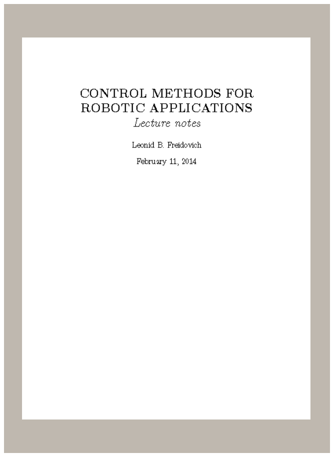
Recommended course literature



Spong, M.W., Hutchinson, S., and Vidyasagar, M.,

Robot Modeling and Control,

John Wiley and Sons, 2006



Lecture notes by Leonid Freidovich

(based on Spong *et al*)

Available on Canvas@Lund

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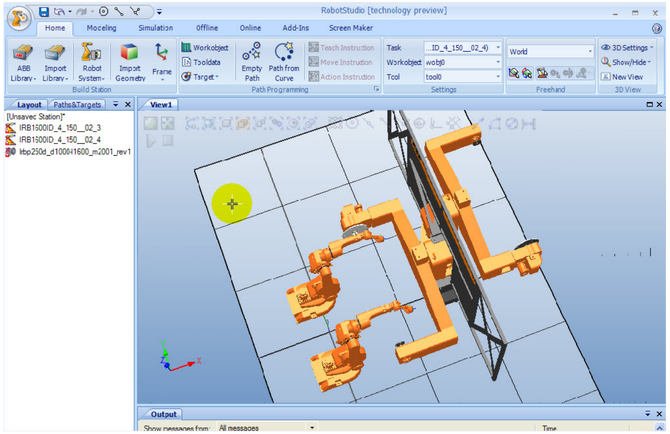
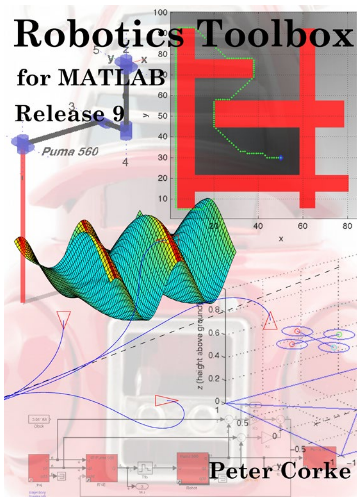
Software



RobotStudio

(PC-based robot simulation, ABB Robotics)

http://new.abb.com/products/robotics/robotstudio/



Matlab/Simulink

http://petercorke.com/Robotics_Toolbox.html
(NOTE! USE version >= 10)

http://en.wikibooks.org/wiki/Robotics_Kinematics_and_Dynamics

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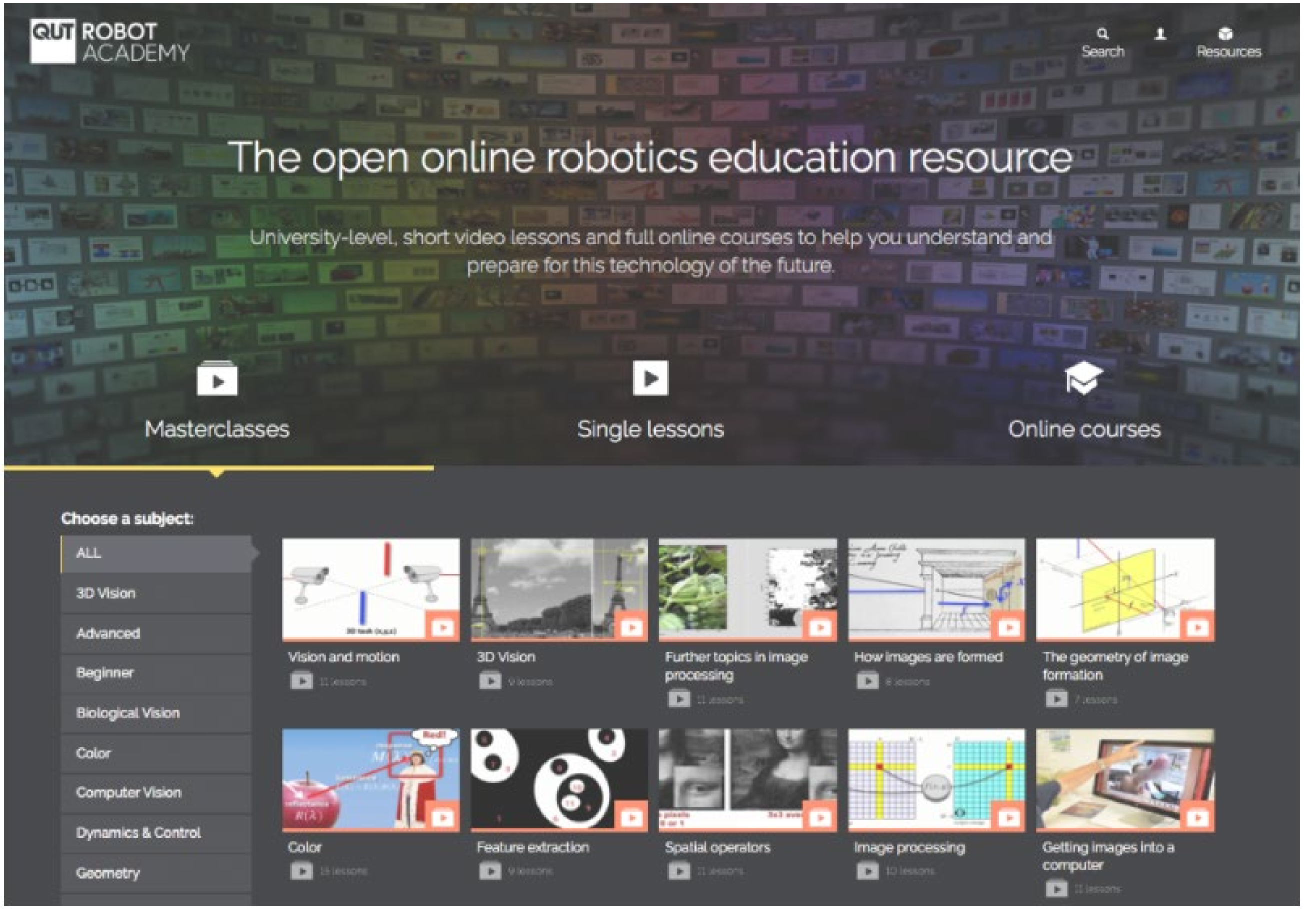
Optional material (recommended)

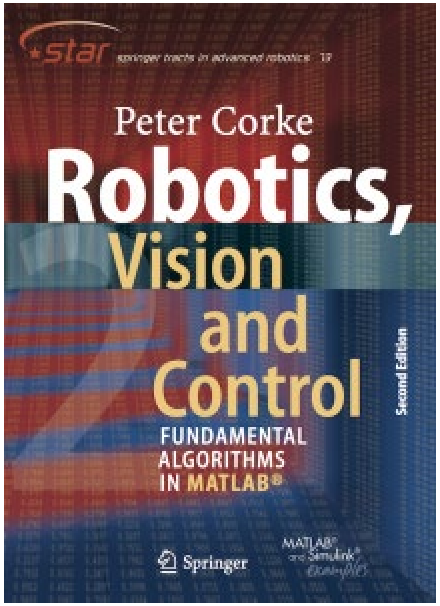
Peter Corke's robot-academy



http://petercorke.com/wordpress/resources/robot-academy

Lund University

Optional reading (recommended)



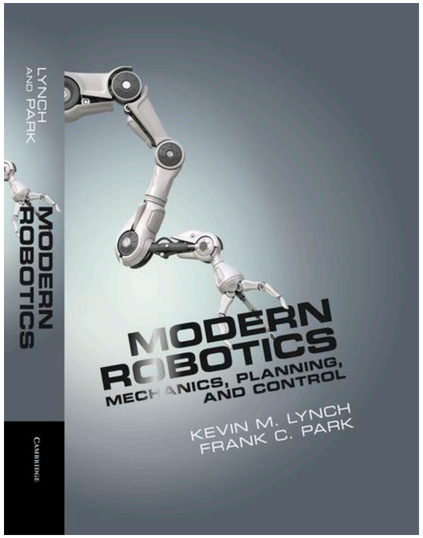
Peter Corke’s robot toolbox (matlab)

http://petercorke.com/Robotics_Toolbox.html
NOTE! USE latest version (10.x)

Available as e-book at
https://link.springer.com/content/pdf/10.1007%2F978-3-319-54413-7.pdf
from LU-network.

Optional reading (recommended)

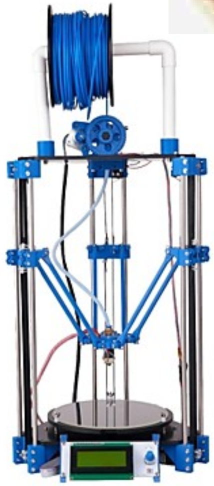
"Modern Robotics: Mechanics, Planning, and Control,"
by Kevin Lynch and Frank Park

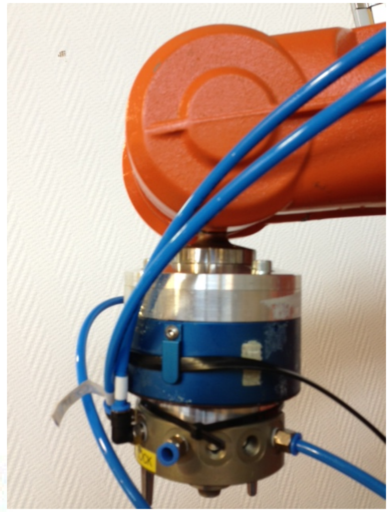


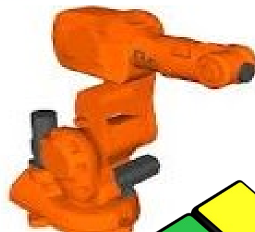
- Available pdf book
- Video lectures
- Rotations based on
  screw-theory and exponential
  representations

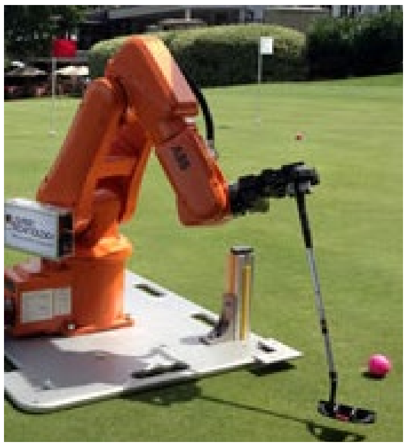
http://hades.mech.northwestern.edu/index.php/Modern_Robotics

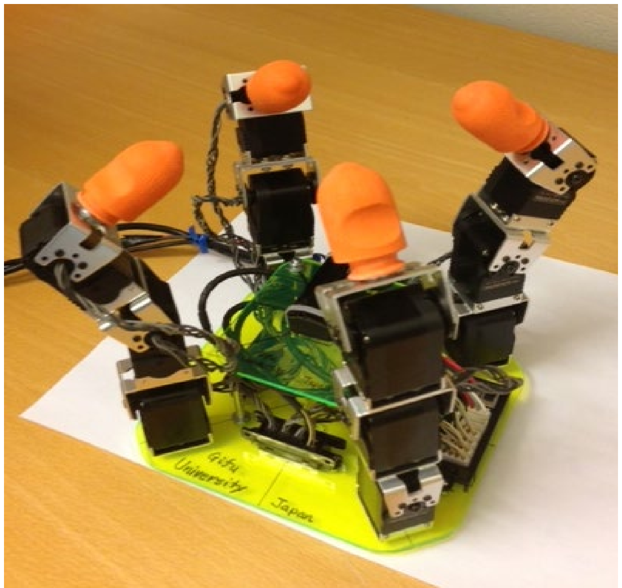
Projects - examples [info/choice week 2]

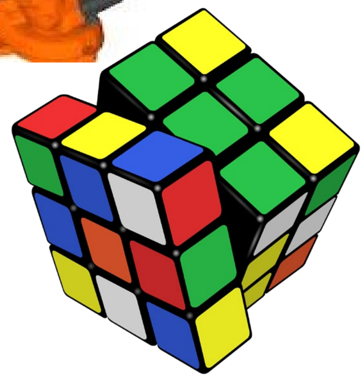












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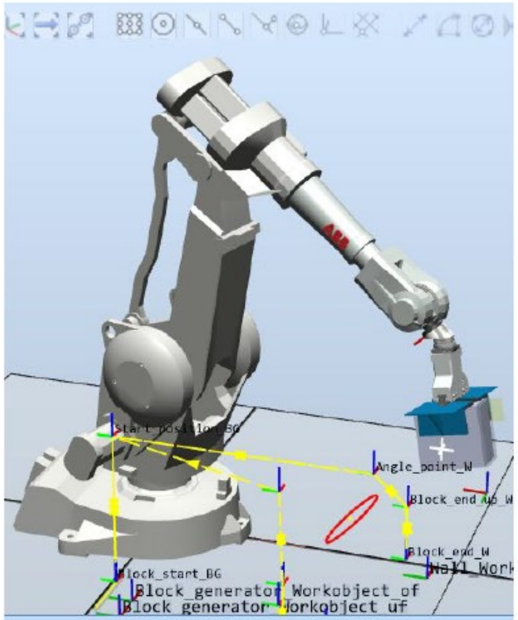
2020: Special projects related to Construction Robotics



To be able to program robust pick-and-place sequences in an accurate brick-laying scenario (see pictures above) it is crucial for very exact placement of the building bricks, that a good enough localization for gripping first can be determined followed by an accurate measurement how the brick was positioned within the gripper.

Compulsory Hands-On exercise

Please sign up for the
first RobotStudio exercise including a **compulsory** hands-on exercise

Alternatives

Thursday	Sept 3,	13.15-15,	IKDC:108
Thursday	Sept 3,	17.15-19,	IKDC:108
Friday	Sept 4,	8.15-10,	IKDC:108

Announcement on Canvas with
direct link to signup-list

Preparation: Read hand-out before coming to the lab!

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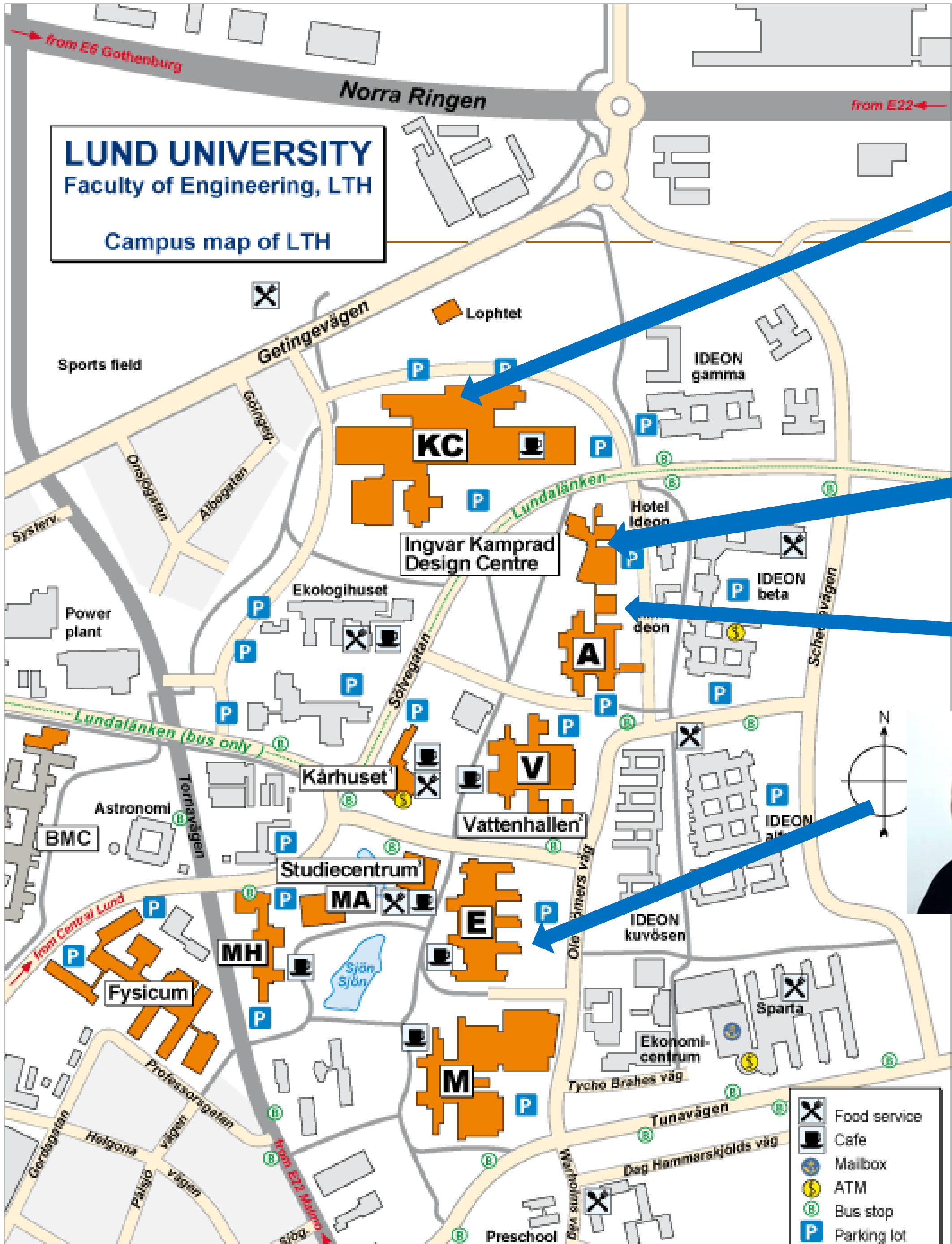
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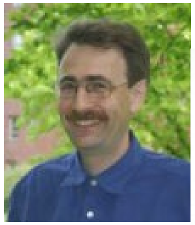
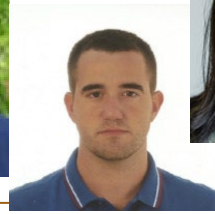
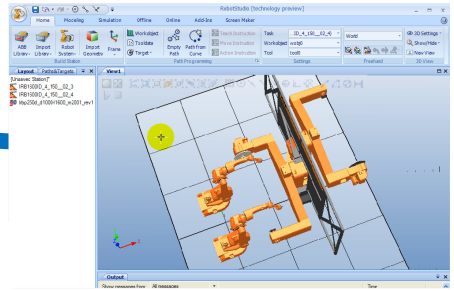
Faculty of Engineering, LTH
Campus map of LTH
from E6 Gothenburg
Norra Ringen
from E22
Getingevägen
Lophtet
Sports field
IDEON gamma
KC
Lundalänken
Hotel Ideon
Ingvar Kamprad Design Centre
Ekologihuset
IDEON beta
Power plant
A
Sölvegatan
Lundalänken (bus only)
Kårhuset
V
Vattenhallen
Astronomi
BMC
Tornavägen
Studiecentrum
MA
E
MH
Fysicum
Sjön Sjön
IDEON kuvösen
Sparta
Ekonomicentrum
M
Tycho Brahes väg
Tunavägen
Dag Hammarskjölds väg
Professorsgatan
Helgona
Preschool
from Central Lund
from E22 Malmö
Food service
Cafe
Mailbox
ATM
Bus stop
Parking lot

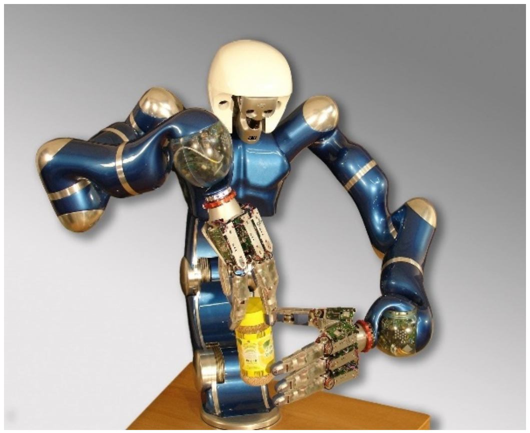






Robots – What kinds of robots?



Industrial robotics
Mobile Robotics
Service robotics
Entertainment
...


Multi-disciplinary:

Nonlinear control, mechatronics, real-time embedded systems...

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Some Robot Classifications

- "Entertainment Robotics"
  - Wheeled and Walking Robots, such as Asimo from Honda
  - Toys such as Aibo from Sony, https://us.aibo.com/
  - Boston dynamics https://www.bostondynamics.com/
- Service Robotics
  - Trilobite - Robot Vacuum Cleaner from Electrolux
  - Husqvarna lawn mower
  - The Helpmate - Hospital Robots
- Industrial Robotics
  - Serial-Type Robots
  - Parallel Kinematic Machines
  - Arc and Spot Welding (Number 1 Application)
  - Spray Painting, Grinding, Milling, Polishing

Lund University and Güdel AG exhibit real-time coordination between robots with significantly different types of kinematics and control systems. Requiring different robots to work together is an example of the heterogeneous situation that is typical at SMEs. The state of the art motion-coordination software is demonstrated by collaborative machining of parts for wooden boxes. Here, a Güdel parallel-kinematic concept robot and a standard ABB serial-kinematic robot complement each other well to solve the task: The parallel robot offers exceptional stiffness and accuracy for machining, and the serial robot can perform both handling and rough-cut machining. These two relate to the project's demonstrator currently deployed at a Swiss woodworking company, with software services being loosely coupled for flexible configuration while supporting tight real-time control loops for efficiency during production.

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https://www.youtube.com/watch?v=1kkXDWQQTlo&list=PLEh-D3GZjSvGk3BMxKbjx9nzmREWeF__j&index=6&t=0s

GÜDEL

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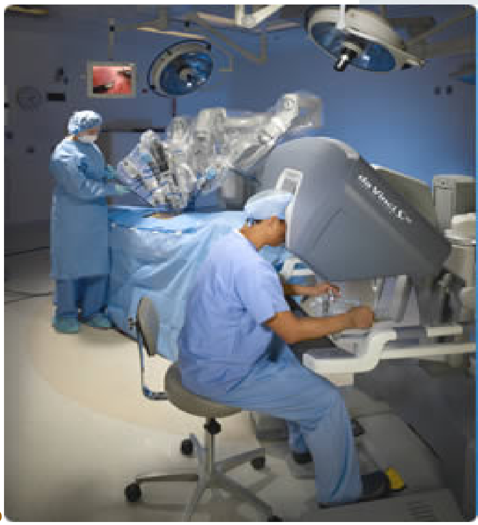
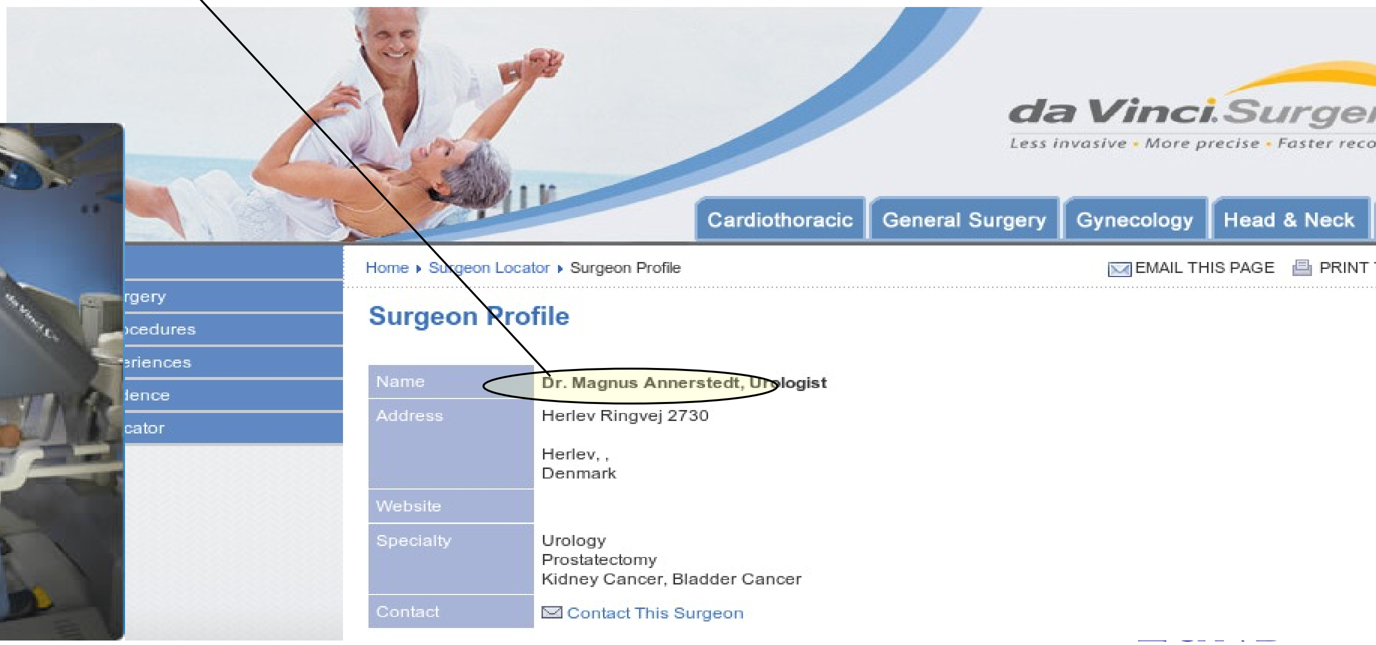
Medical robotics

https://www.youtube.com/watch?v=7sTfD_mStwE

da Vinci-robot by Intuitive surgery

[“Stability of Haptic Obstacle Avoidance and Force Interaction”, R Johansson, M Annerstedt, A Robertsson (2009)]





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https://www.youtube.com/watch?v=C17-bGquIjI

Robotics in this course

- The following conceptual problems must be resolved to make a robot succeed in performing a typical task:
  - Forward Kinematics
  - Inverse Kinematics
  - Velocity Kinematics/Jacobians
  - Dynamics
  - Path Planning and Trajectory Generation
  - Motion Control
  - (Force Control)
  - Sequence programming (and task description)

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Robotics

- The application, tooling, design of robots…

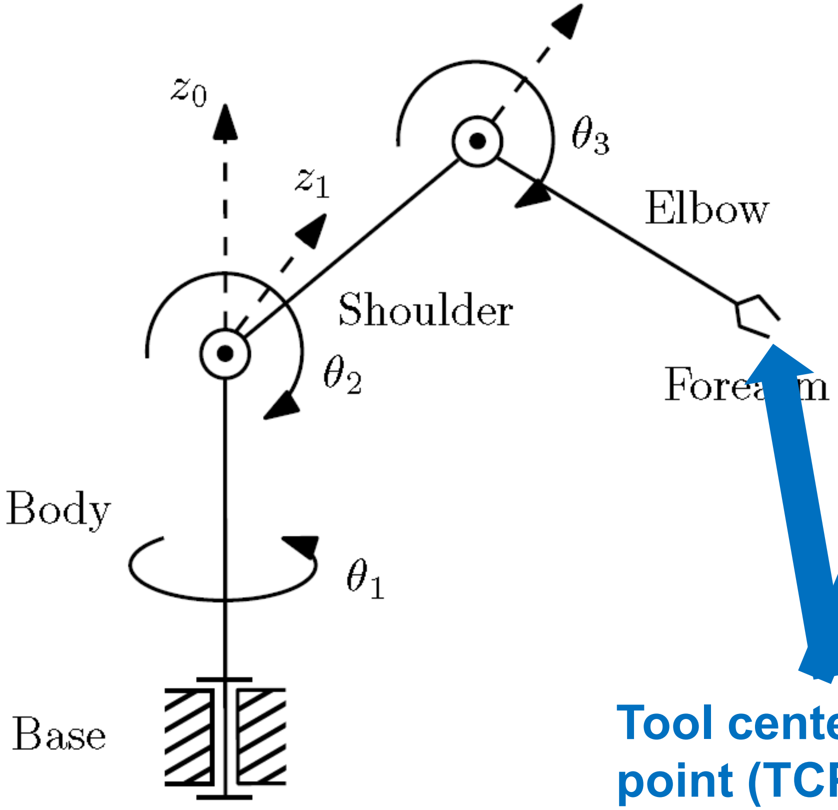
Degrees of freedom

- 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

Example: The GiftWrapper

Robot arm

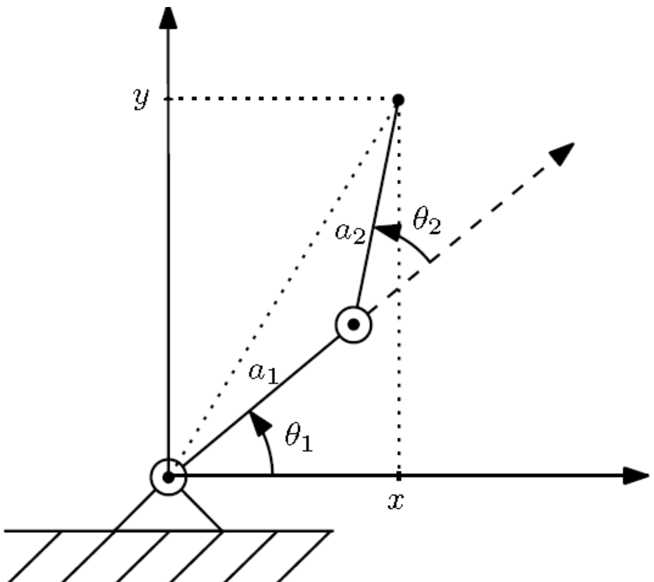


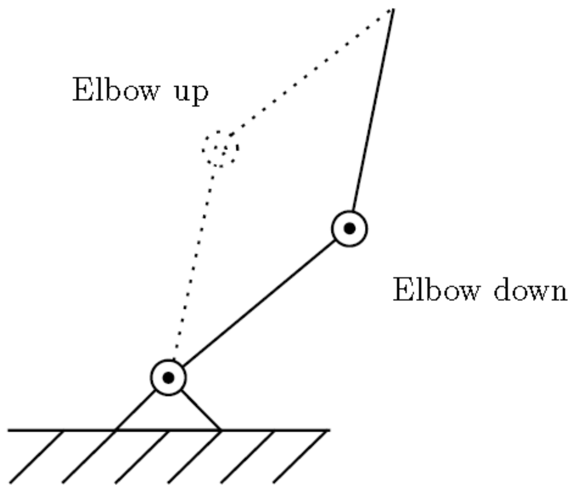
Tool center point (TCP)

Forward and Inverse kinematics

- **Forward kinematics:**
  - Given angles find tooltip pose (pose: position+orientation)
- **Inverse kinematics:**
  - Given desired tool pose find joint angles

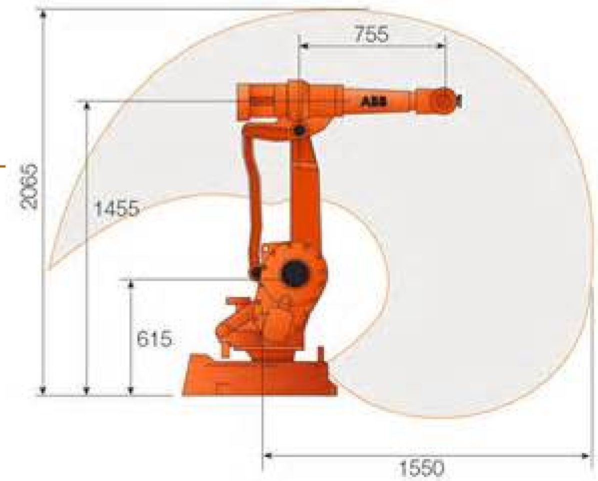
  Possibly several different solutions

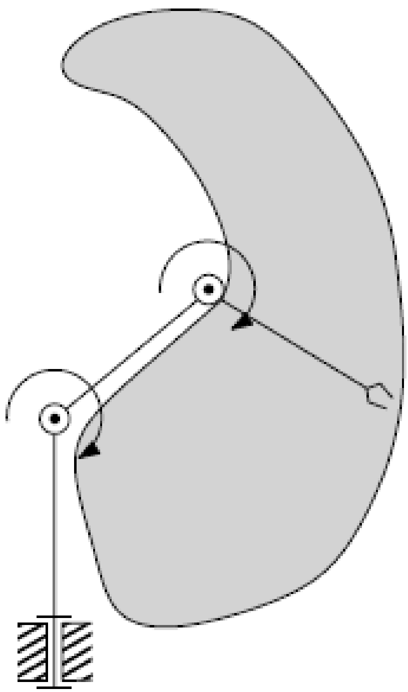


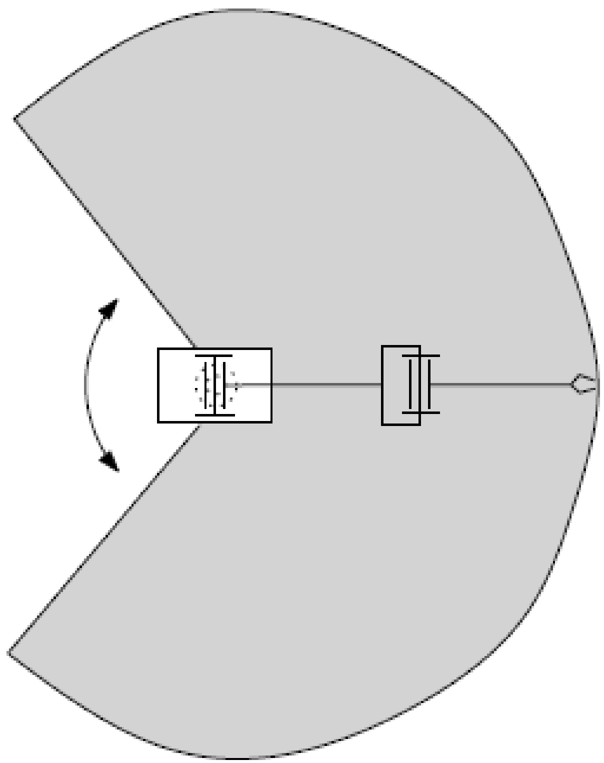


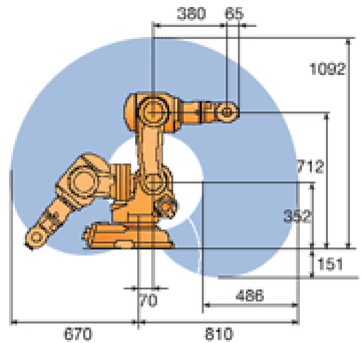
Workspace

- Joint limitation taken into account



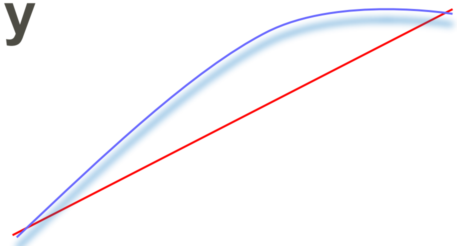






Robot motions

- Point-to-point motion
  - **MoveL** - Moves the tooltip (TCP) of the robot linearly
  - **MoveJ – "joint interpolation" (usually** ends up with *curved Cartesian motion*)



- Path generation
  - Geometric path
- Trajectory tracking
  - Geometric path AND time matters
  - At what time are you in what position with what velocity/acc etc

Fanta Challenge
http://www.youtube.com/watch?v=SOESSCXGhFo

Ethical Issues

- A company should not use robots to replace workers, unless they are forced to by global competition. What is your opinion?
- A robot should do hazardous and strenuous jobs that workers cannot or do not want to do.
- Robotics can create new jobs - in engineering and science – and save jobs in high-cost countries.
- Robotics can increase product quality and repeatability.
- Robotics is finding new applications in the domestic service market which potentially can give people more spare time.

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robots-create-jobs/

IFR
International
Federation of
Robotics

Menu

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  - Work in High Wage Countries
  - Work Impossible for Humans
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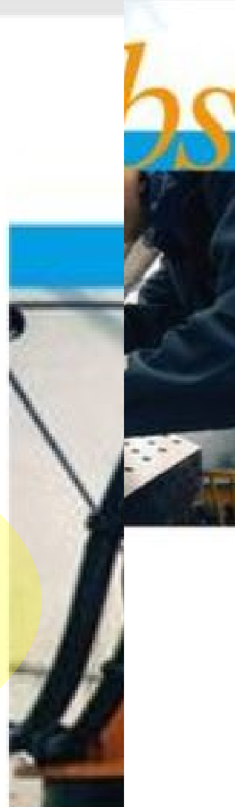
Robots Create Jobs

ROBOTICS will be a major driver for global job creation over the next five years. The announcement is based on a study conducted by the market research firm, Metra Martech, "Positive Impact of Industrial Robots on Employment".

One million industrial robots currently in operation have been *directly* responsible for the creation of close to three million jobs, the study concluded. A growth in robot use over the next five years will result in the creation of one million high quality jobs around the world. Robots will help to create



Advantages of robotics

- Reduced cycle times (in some cases from 30 mins to 3 mins – replacing slower TIG welders with MIG welders)
- One twin robot welding cell can replace 10 manual stations (frees up floor space and welding equipment)
- Less environmental damage – as fume extraction from one station is easier to handle than 10 stations.
- Consistent and repeatable product quality
- Easier to keep good employees because of interesting technology environment

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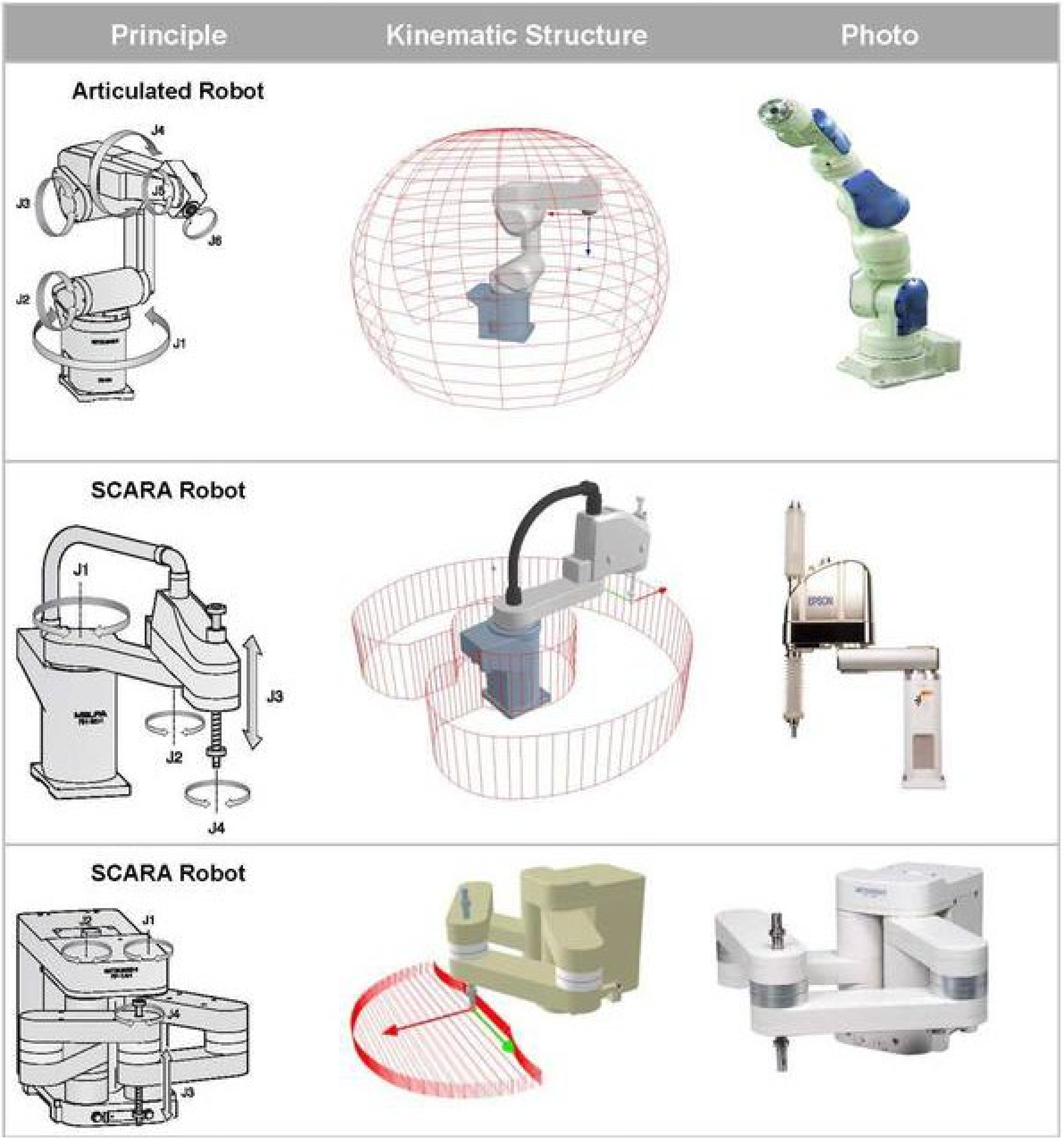
Industrial robot

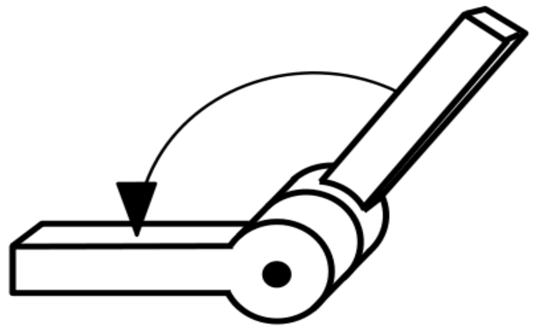
Industrial robot as defined by ISO 8373:
An **automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes**, which may be either fixed in place or mobile for use in industrial automation applications.

Reprogrammable: whose programmed motions or auxiliary functions may be changed without physical alterations;

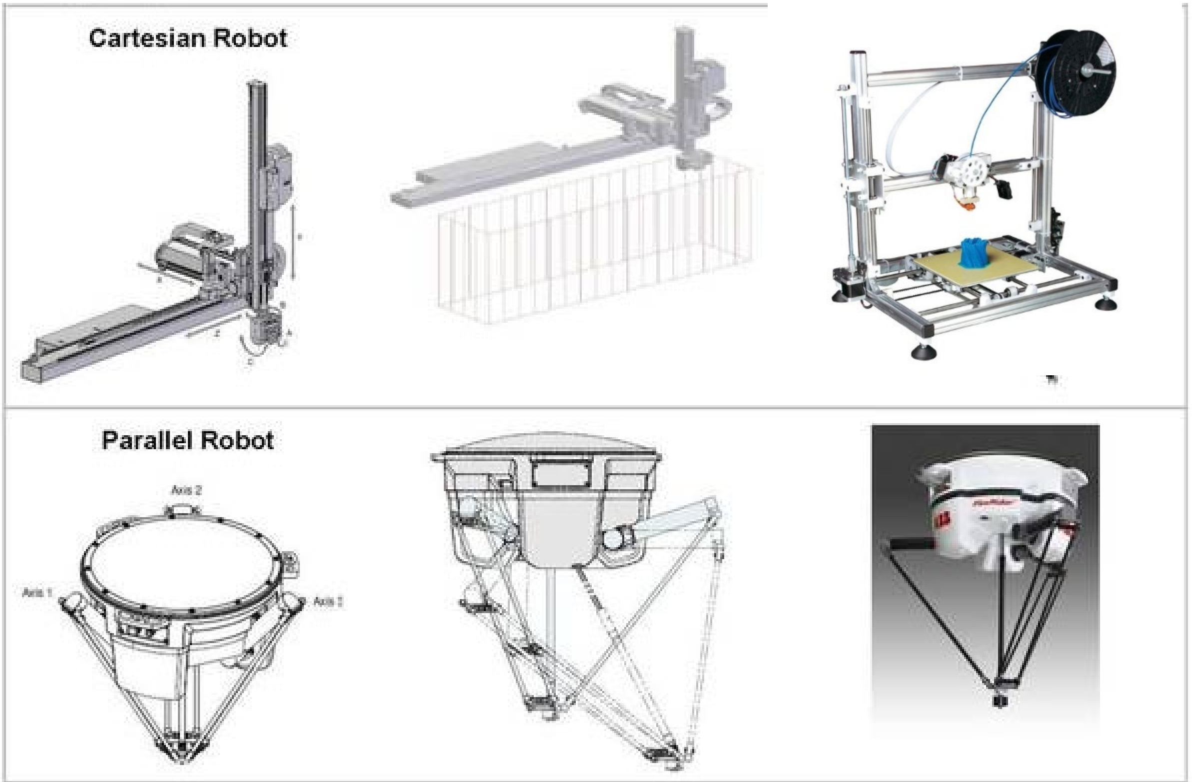
Multipurpose: capable of being adapted to a different application with physical alterations;

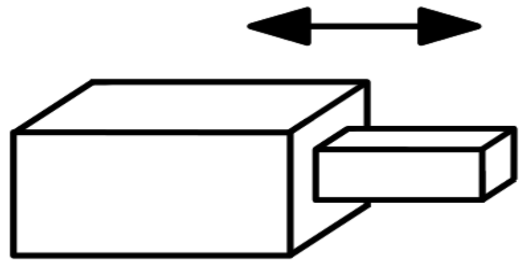
Physical alterations: alteration of the mechanical structure or control system except for changes of programming cassettes, ROMs, etc.





Revolute joints





Prismatic joints

Flexpicker: https://www.youtube.com/watch?v=cajVzpJKjdw

PKM Gantry-Tau:
http://www.smerobot.org/15_final_workshop/download/half%20resolution/D1_Parallel_Kinematic_512x288_500kBit.wmv

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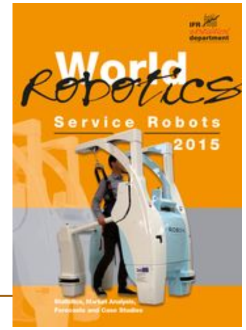
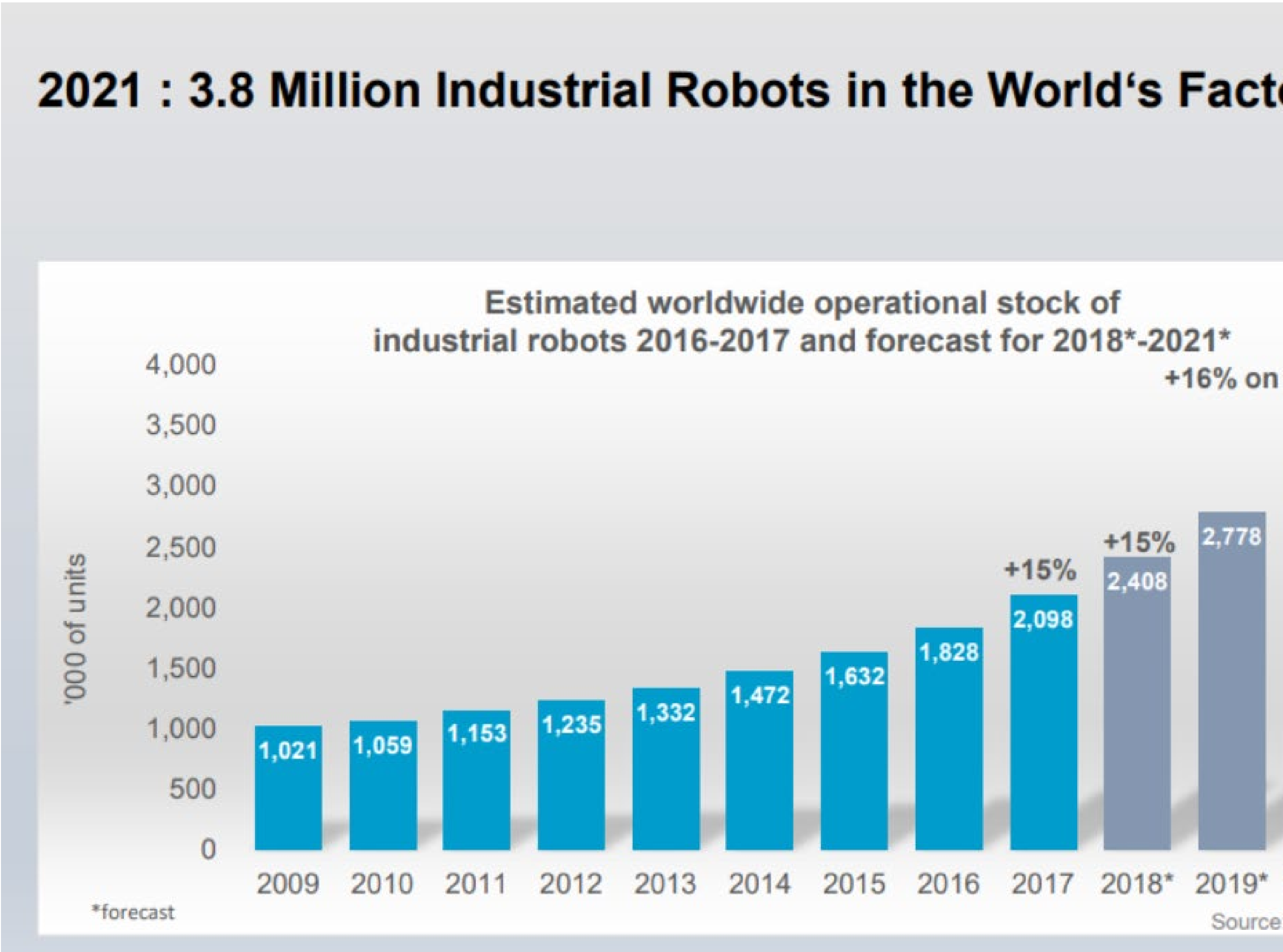
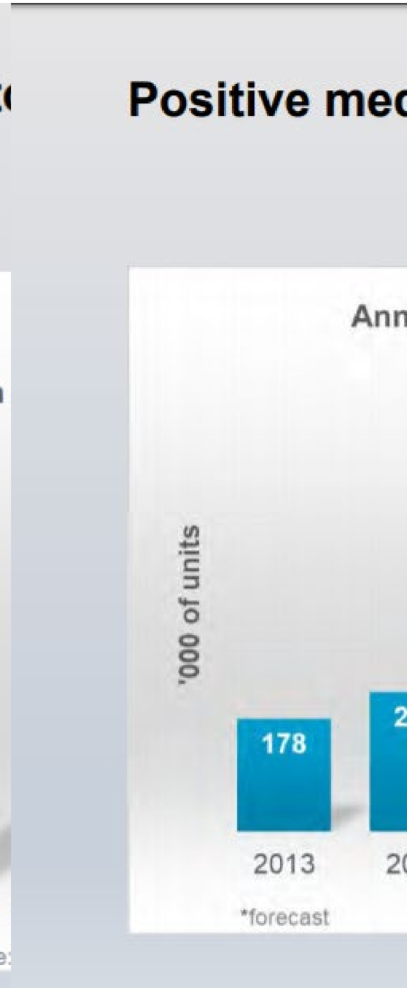
Some statistics

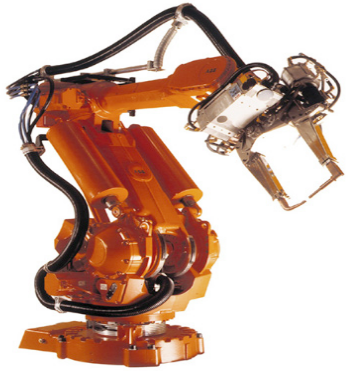


http://www.ifr.org/industrial-robots/statistics/



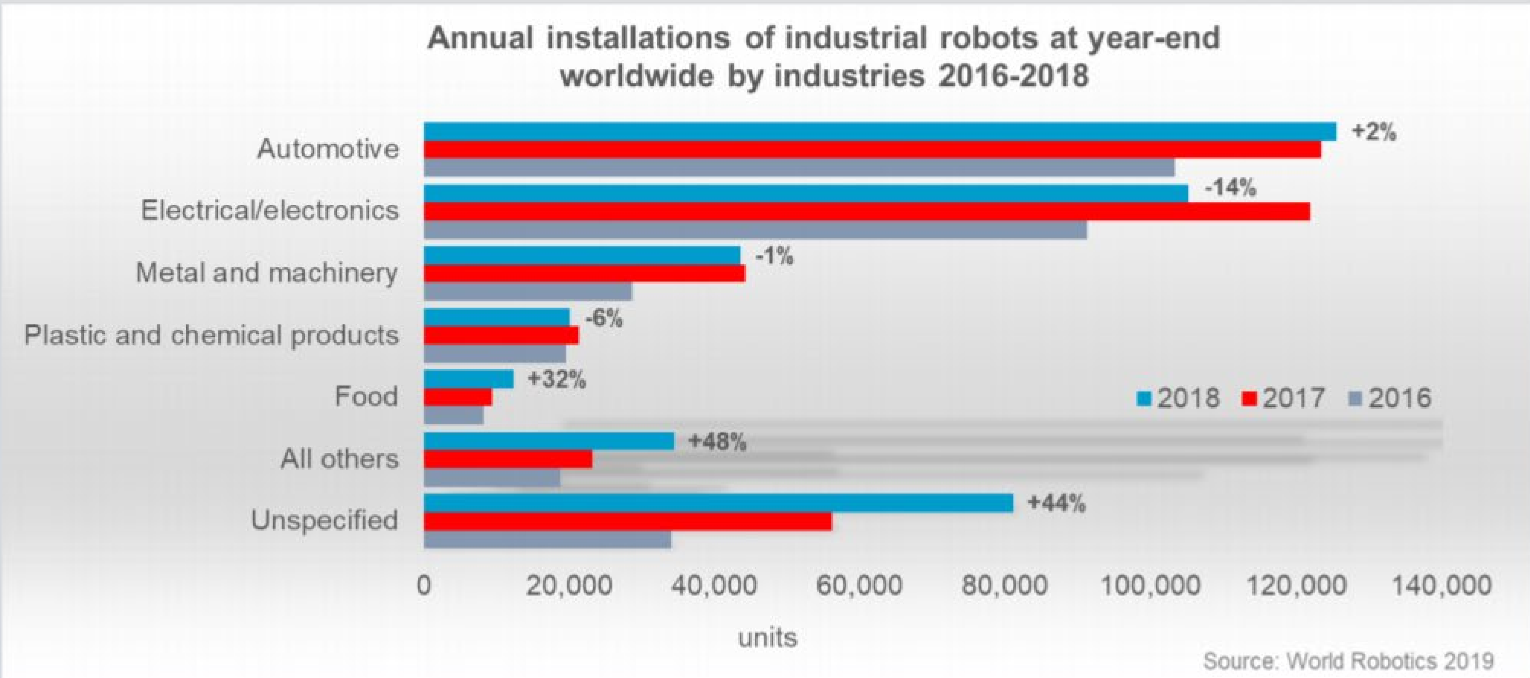


Industrial areas

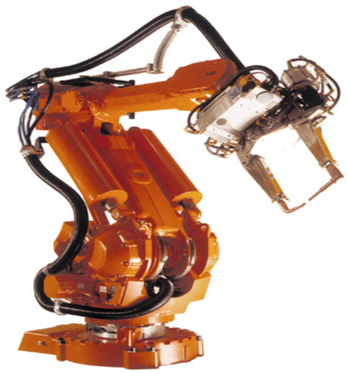


IFR International Federation of Robotics

Key Industries : Automotive, Electronics & Metals



Industrial areas



Technological Developments expanding Robot Adoption

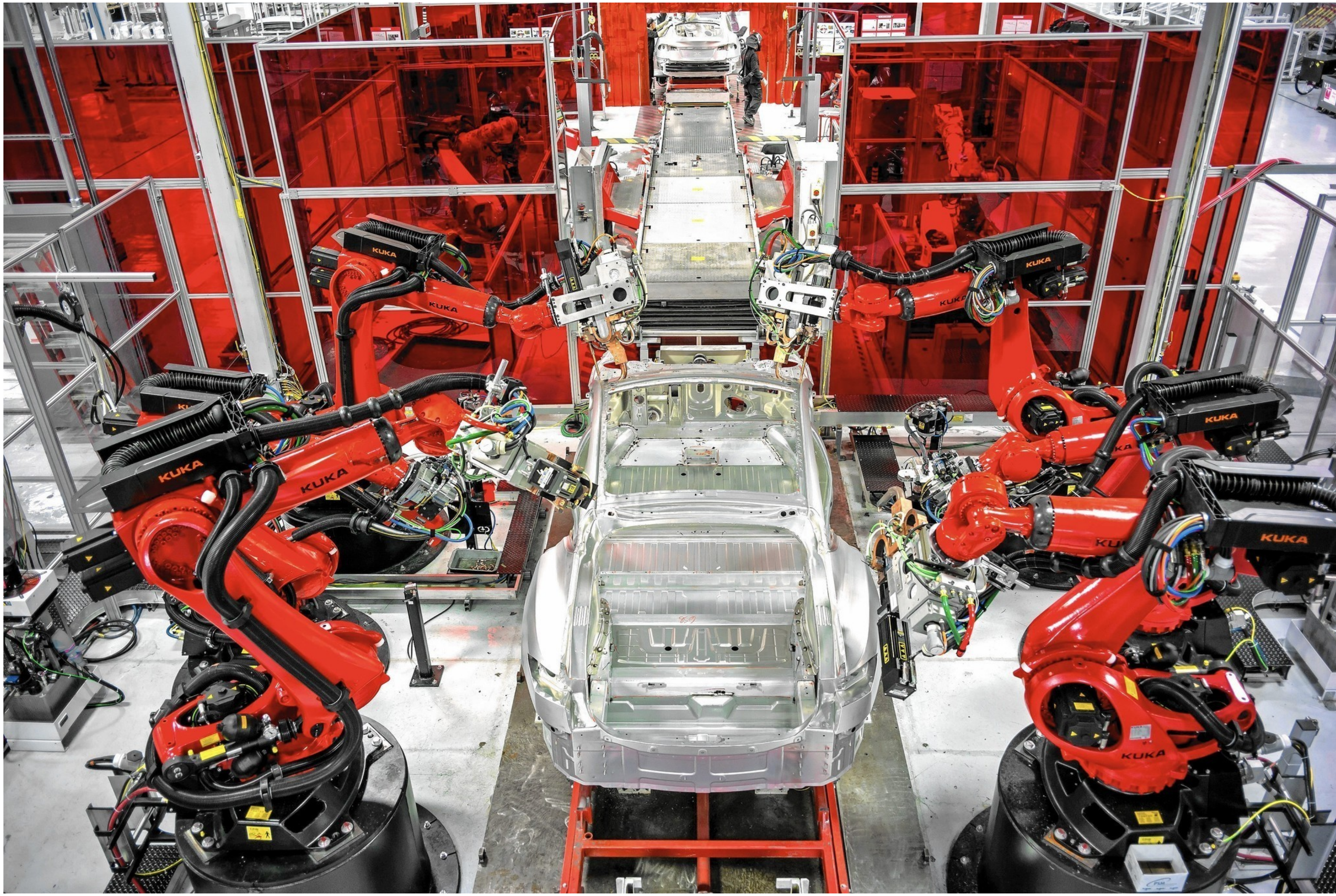
Today

- More intelligent components, e.g. Smart Grippers
- Greater Connectivity, e.g. “Plug & Play” Interfaces and Cloud Computing
- Easier to Use, e.g. “Programming by Demonstration”

Tomorrow

- “Machine learning” enables Robots ….
  - to learn by trial-and-error or by video demonstration.
  - to self-optimise.
  - to communicate with other machines to improve entire processes.
- New business models, e.g. Robots as a Service (RaaS)

Automotive example: production of Tesla S



https://www.youtube.com/watch?v=8_lfxPI5ObM

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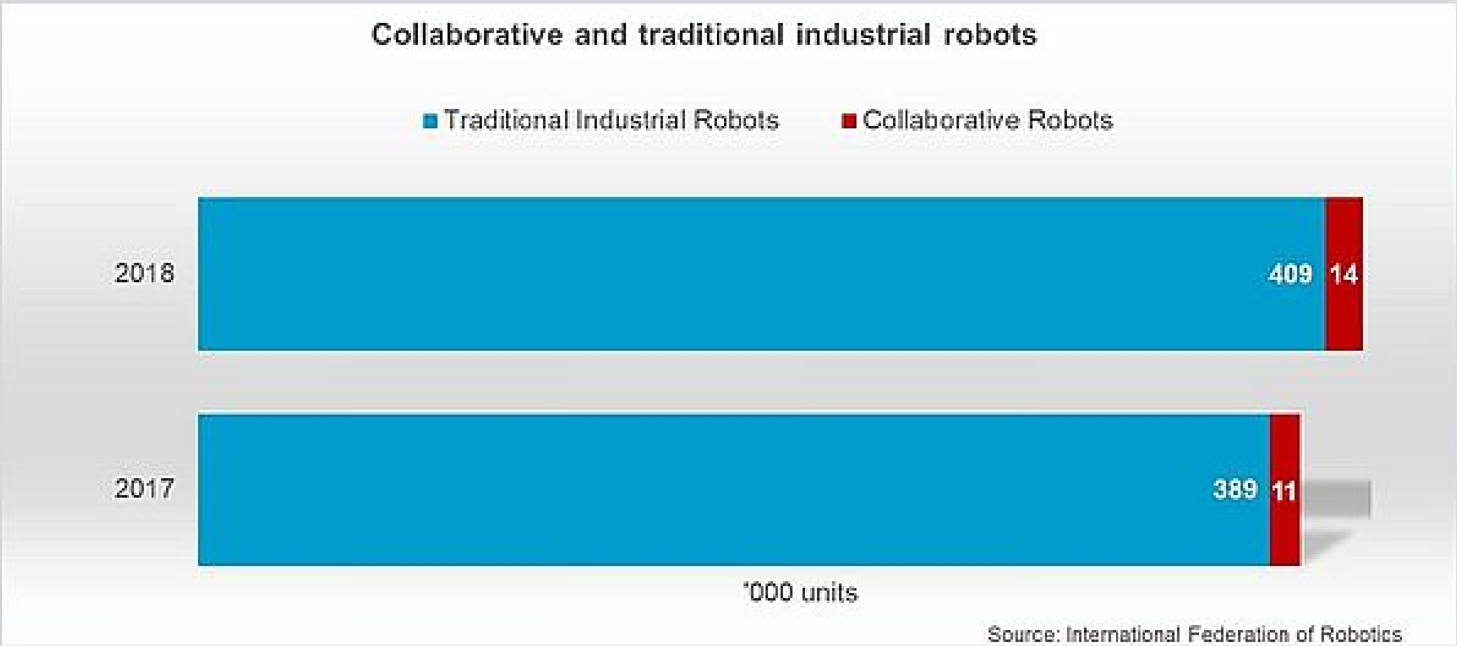
Human-machine collaboration

- The break-through of the human-machine collaboration is just beginning
- People without experience in using robots can program and integrate a robot in the process because it
  - is capable of understanding human-like instructions
  - has modular plug-and-produce components
- Major challenge safety
  - The robot is working close to the worker without a fence
  - Lightweight robots with integrated vision guidance and better sensor
  - ISO: Technical Specification for collaboration of humans and industrial robots in order to provide reliable safety requirements.

Collaborative industrial robots still a niche



New Industrial Robot Designs

- **Control engineers and mechanical design engineers must work together at concept stage (controller tuning stage too late)**
- **Parallel (stiff) designs increase resonance frequencies**
- **Control structures should be tested on elasticity models**

  already at concept stage (e.g., Matlab/Simulink)

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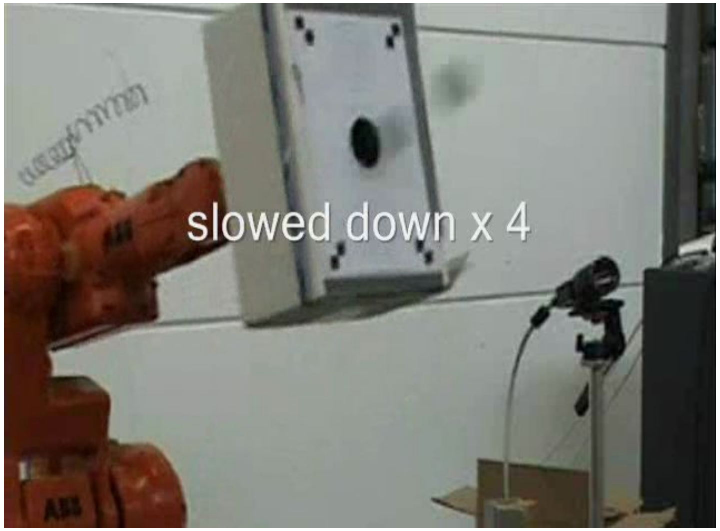
Force and vision – reaction time crucial

Applications and enabling technology ….



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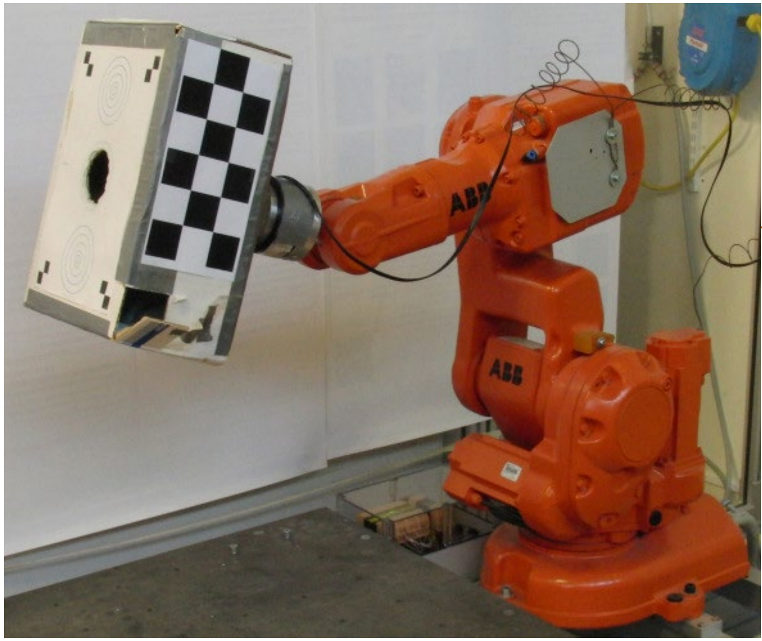
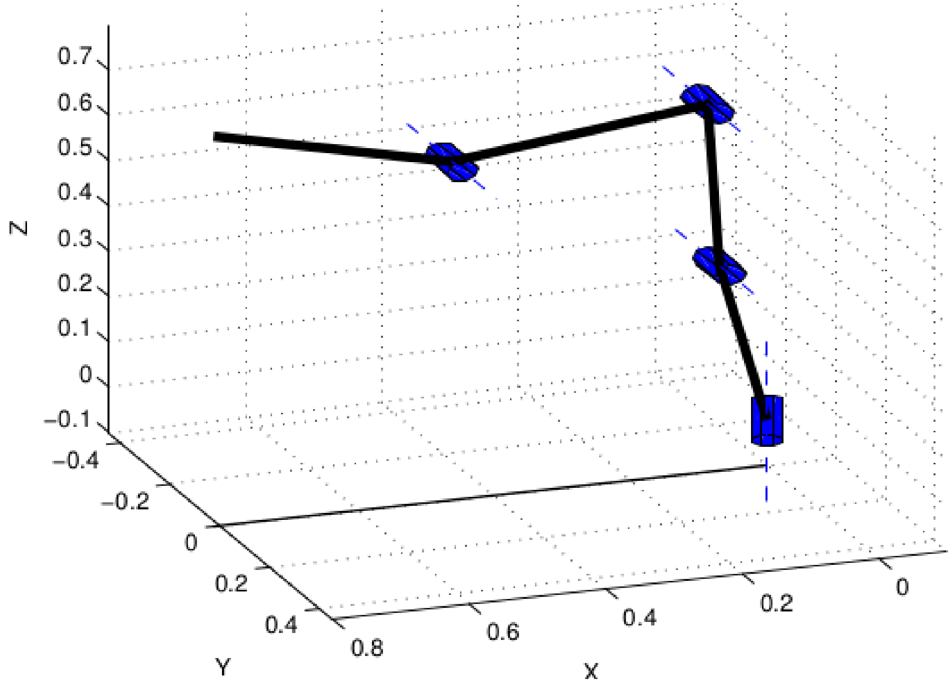
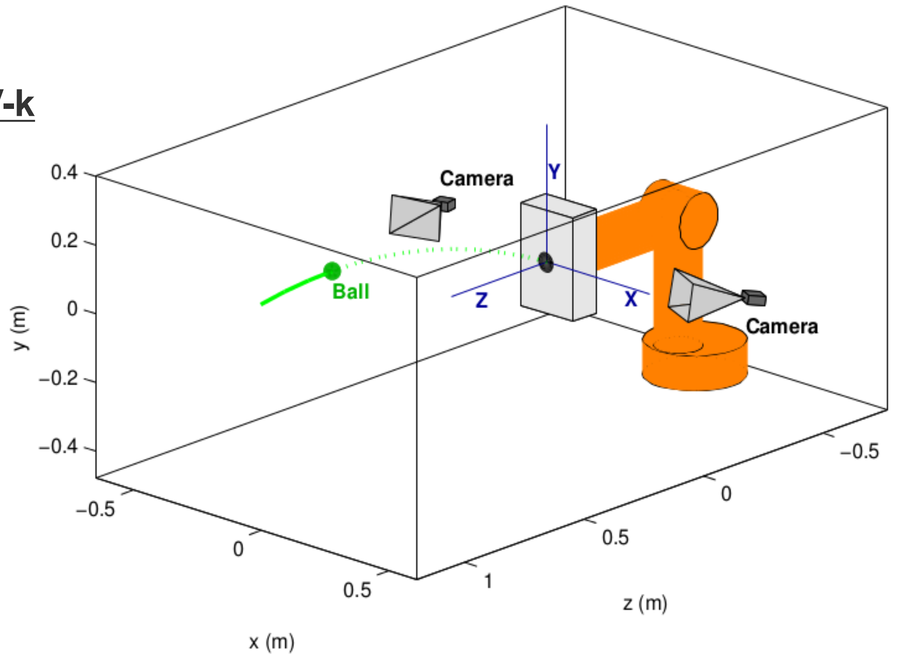




[Ball-and-dart-catching robot](https://www.youtube.com/watch?v=XP7yWhN6V-k)
https://www.youtube.com/watch?v=XP7yWhN6V-k



Robotics in this course

- The following conceptual problems must be resolved to make a robot succeed in performing a typical task:
  - Forward Kinematics
  - Inverse Kinematics
  - Velocity Kinematics/Jacobians
  - Dynamics
  - Path Planning and Trajectory Generation
  - Motion Control
  - (Force Control)
  - Sequence programming (and task description)

Robot task example

[Lec Notes, Ch 1.4]

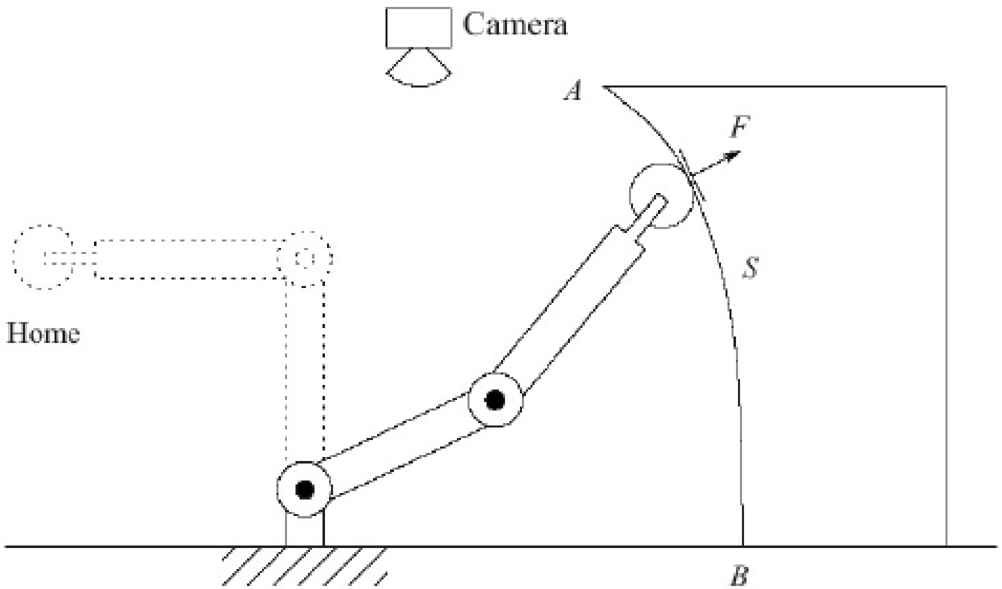


Figure 1.19: Two-link planar robot example. Each chapter of the text discusses a fundamental concept applicable to the task shown.

Forward kinematics

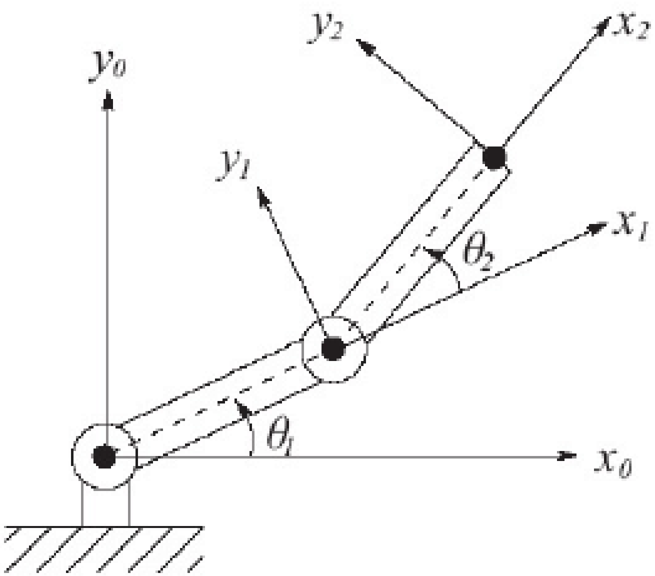


Figure 1.20: Coordinate frames attached to the links of a two-link planar robot. Each coordinate frame moves as the corresponding link moves. The mathematical description of the robot motion is thus reduced to a mathematical description of moving coordinate frames.

Inverse kinematics

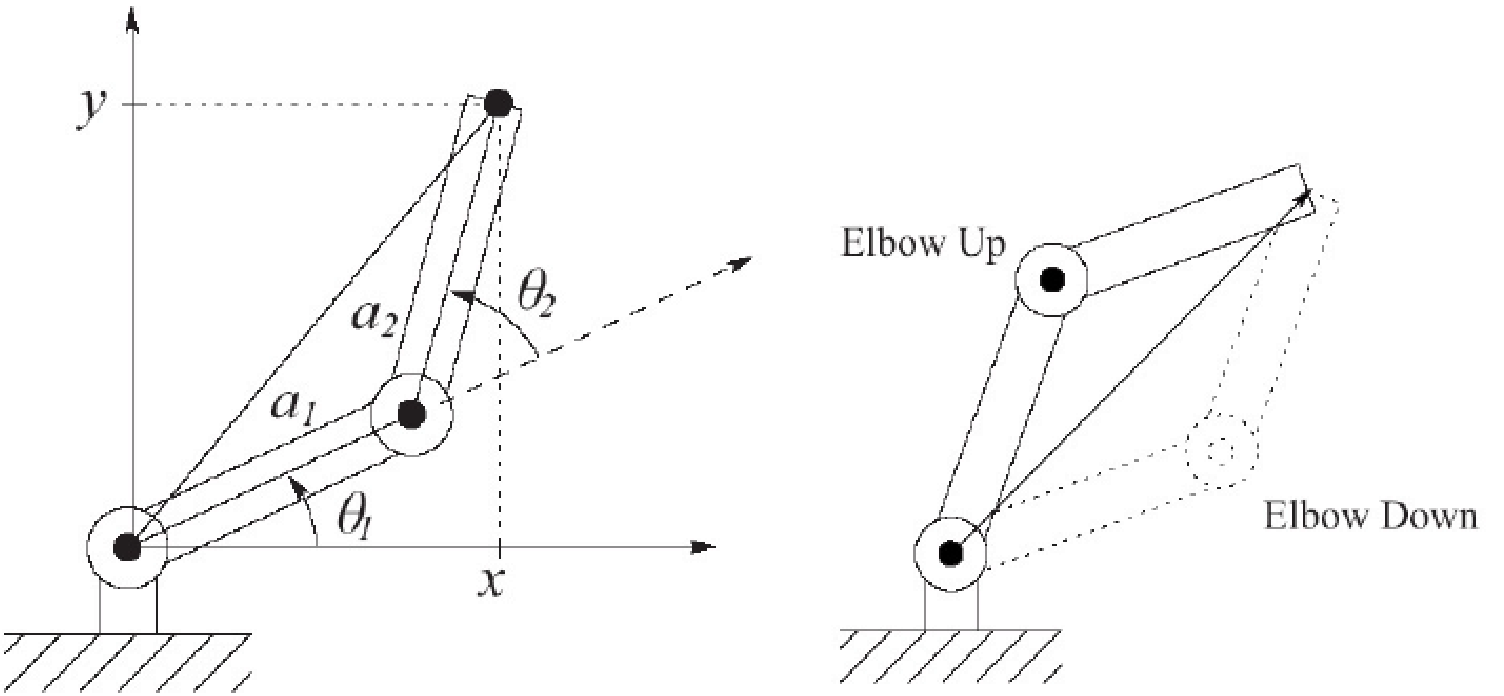
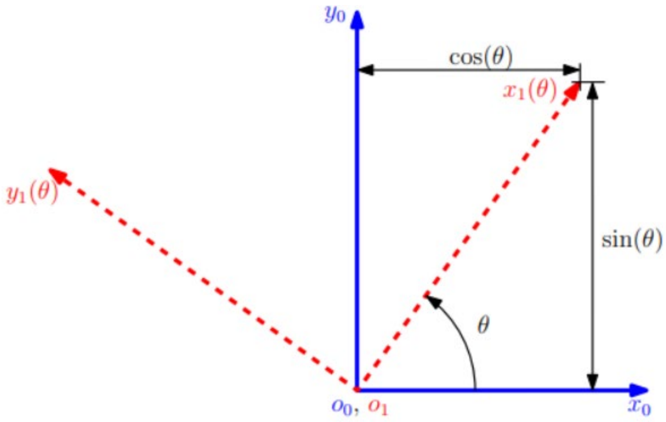
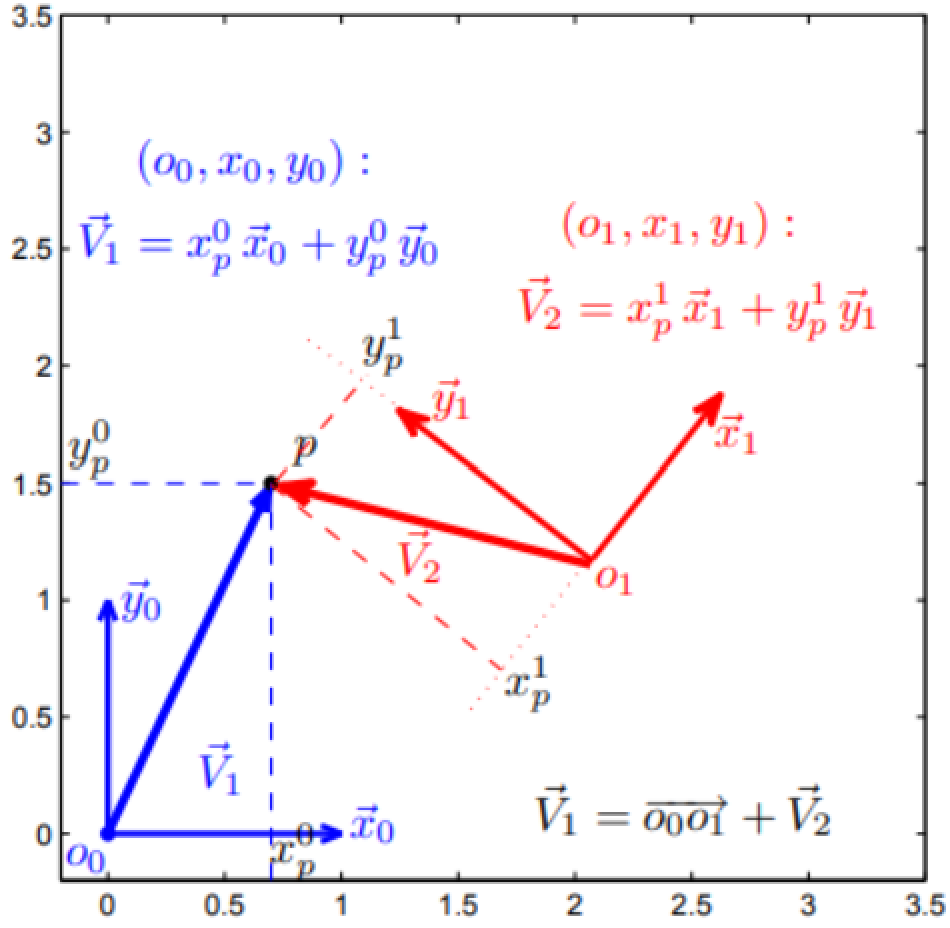


Figure 1.21: The two-link elbow robot has two solutions to the inverse kinematics except at singular configurations, the elbow up solution and the elbow down solution.

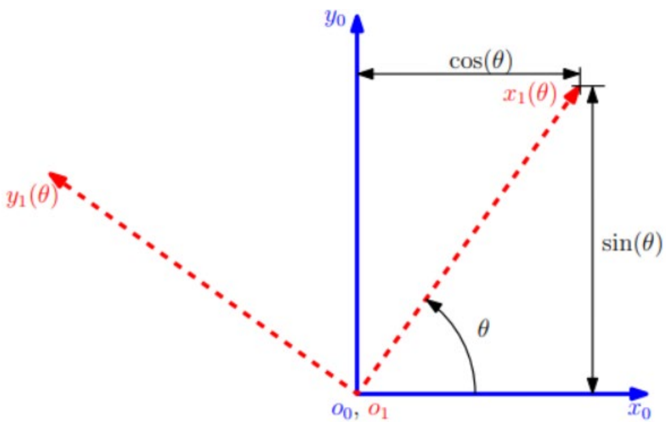
Rotations within a frame

Descriptions in different frames

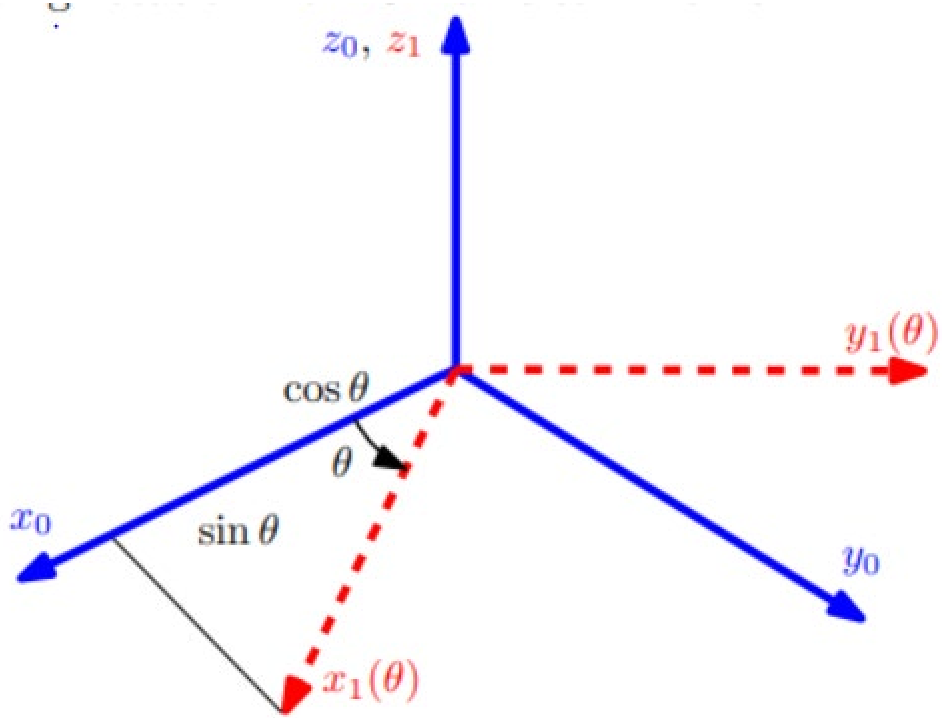




Rotations in 2D

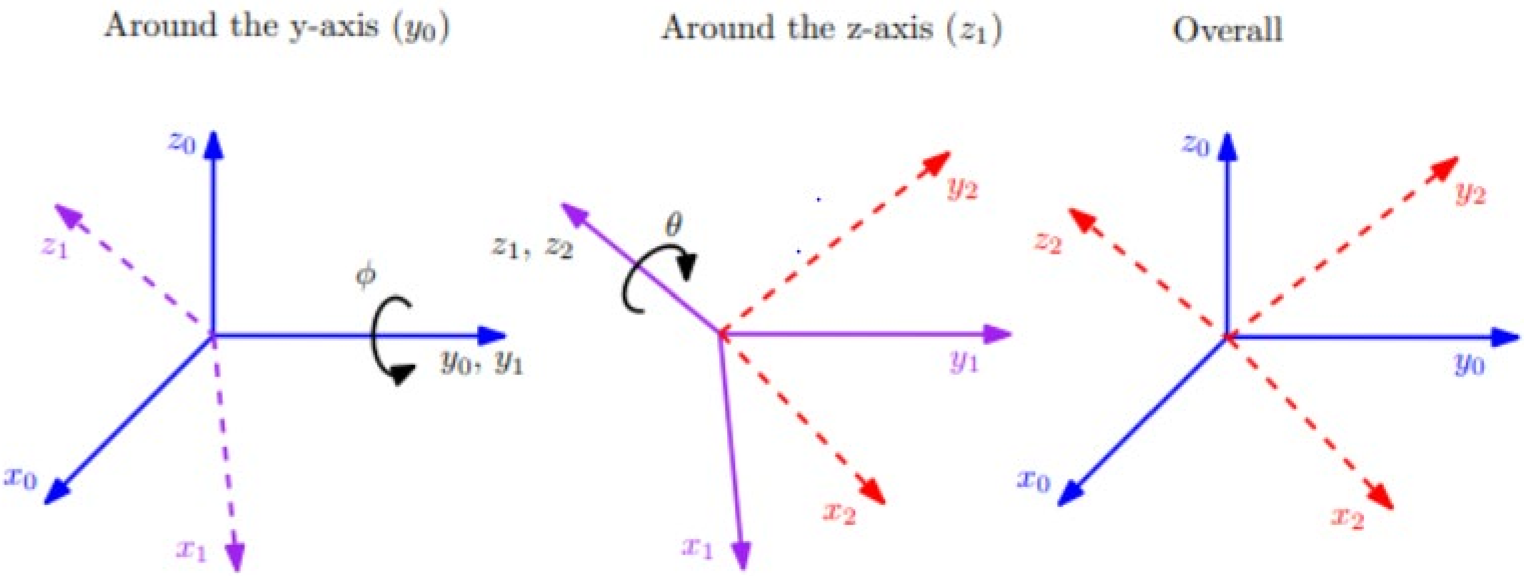


Rotations in 3D



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

Composition of rotations



The rotations around the current $\boldsymbol{y}$-axis and $\boldsymbol{z}$-axis are basic rotations

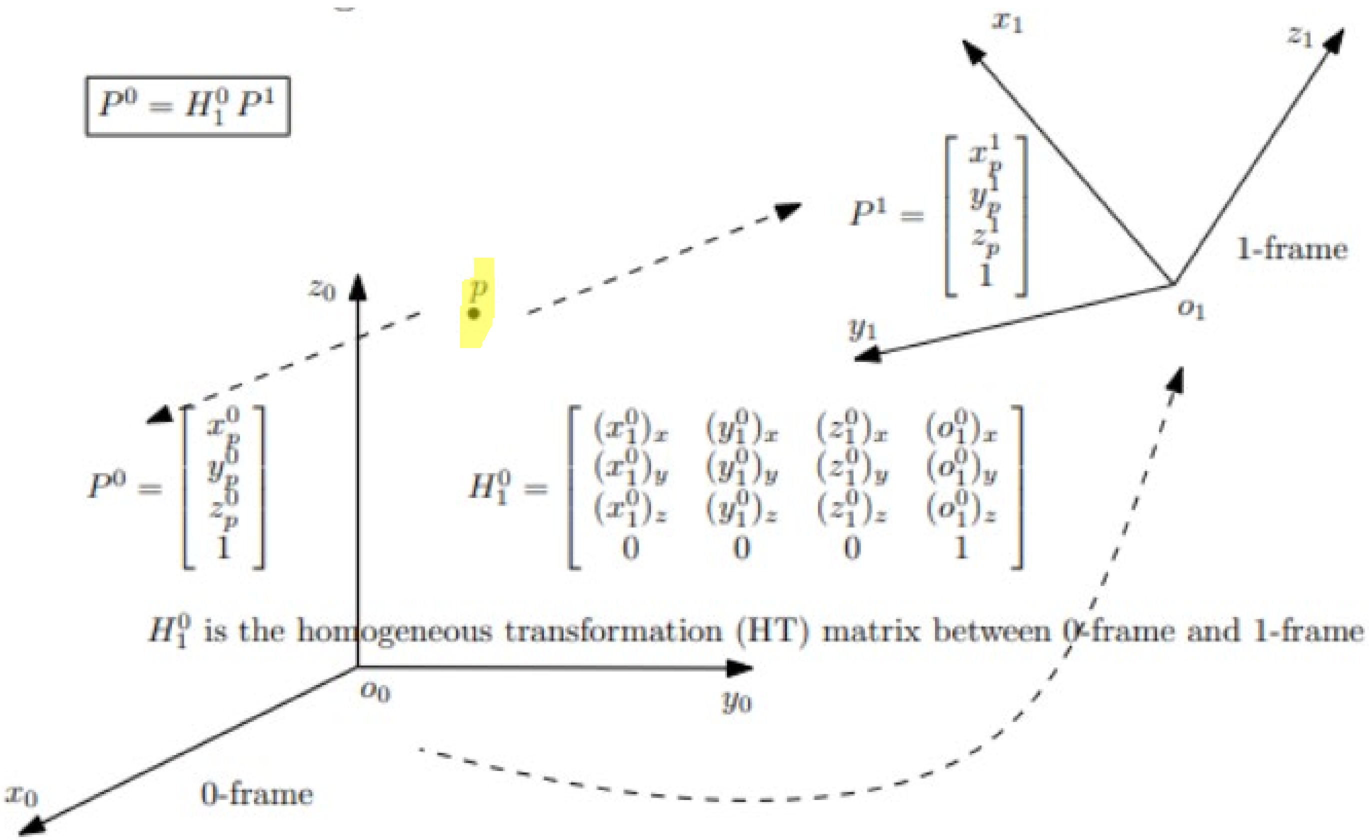
$$\boldsymbol{R}_{y_0,\phi} = \begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix} = \boldsymbol{R}_1^0, \quad \boldsymbol{R}_{z_1,\theta} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} = \boldsymbol{R}_2^1$$

Therefore, the overall rotation is $\boldsymbol{R}_2^0 = \boldsymbol{R}_1^0 \boldsymbol{R}_2^1$, i.e.

$$\boldsymbol{R}_2^0 = \underbrace{\boldsymbol{R}_{y_0,\phi}}_{\text{first}} \underbrace{\boldsymbol{R}_{z_1,\theta}}_{\text{second}} = \begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Frame-to-frame: rotations and translation

$$\boxed{P^0 = H_1^0 P^1}$$



$$P^1 = \begin{bmatrix} x_p^1 \\ y_p^1 \\ z_p^1 \\ 1 \end{bmatrix}$$

$$P^0 = \begin{bmatrix} x_p^0 \\ y_p^0 \\ z_p^0 \\ 1 \end{bmatrix} \qquad H_1^0 = \begin{bmatrix} (x_1^0)_x & (y_1^0)_x & (z_1^0)_x & (o_1^0)_x \\ (x_1^0)_y & (y_1^0)_y & (z_1^0)_y & (o_1^0)_y \\ (x_1^0)_z & (y_1^0)_z & (z_1^0)_z & (o_1^0)_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

H_1^0 is the homogeneous transformation (HT) matrix between 0-frame and 1-frame

$$\boxed{\begin{bmatrix} x_p^0 \\ y_p^0 \\ z_p^0 \\ 1 \end{bmatrix} = \begin{bmatrix} (x_1^0)_x & (y_1^0)_x & (z_1^0)_x & (o_1^0)_x \\ (x_1^0)_y & (y_1^0)_y & (z_1^0)_y & (o_1^0)_y \\ (x_1^0)_z & (y_1^0)_z & (z_1^0)_z & (o_1^0)_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_p^1 \\ y_p^1 \\ z_p^1 \\ 1 \end{bmatrix}}$$

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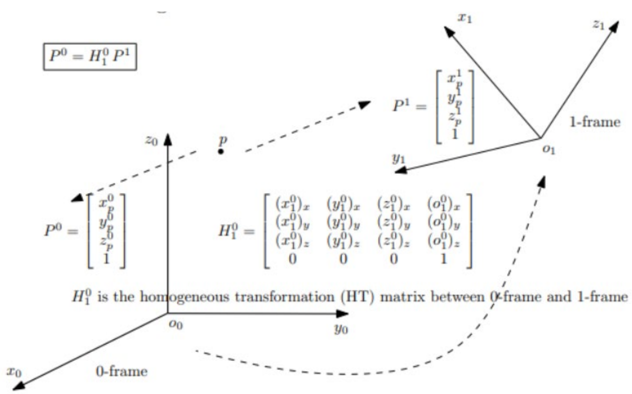


$$\boldsymbol{P}^0 = \begin{bmatrix} \boldsymbol{p}^0 \\ 1 \end{bmatrix} = \begin{bmatrix} \boldsymbol{R}_1^0 \boldsymbol{p}^1 + \boldsymbol{d}^0 \\ 1 \end{bmatrix} = \underbrace{\begin{bmatrix} \boldsymbol{R}_1^0 & \boldsymbol{d}^0 \\ 0_{1\times 3} & 1 \end{bmatrix}}_{\boldsymbol{H}_1^0} \underbrace{\begin{bmatrix} \boldsymbol{p}^1 \\ 1 \end{bmatrix}}_{\boldsymbol{P}^1}$$

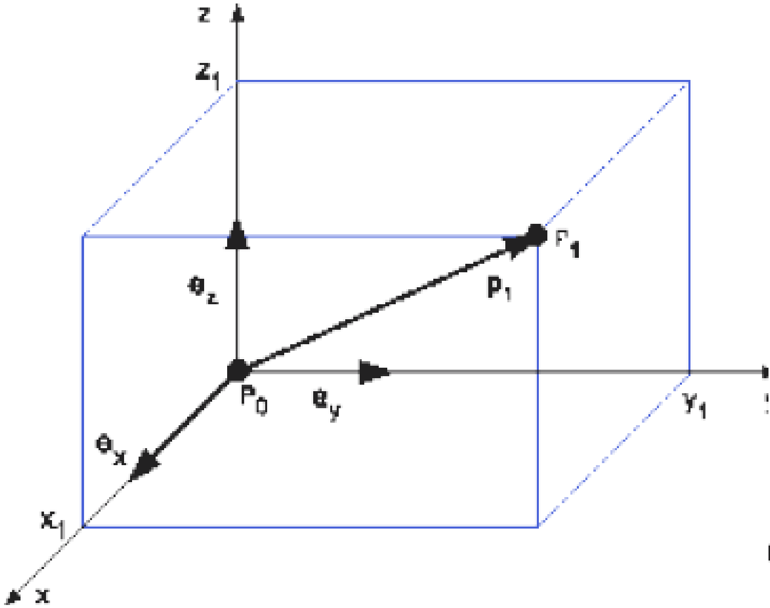
and the change of coordinates formula

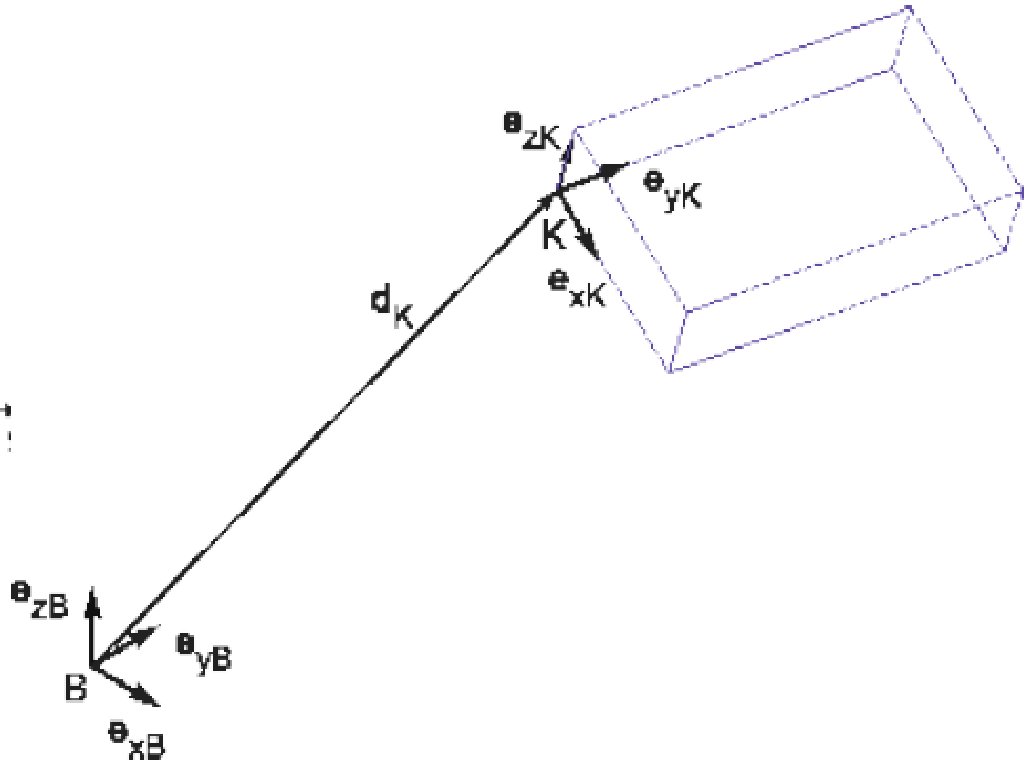
$$\boldsymbol{p}^0 = \boldsymbol{R}_1^0 \boldsymbol{p}^1 + \boldsymbol{d}^0 \qquad \text{becomes} \qquad \boxed{\boldsymbol{P}^0 = \boldsymbol{H}_1^0 \boldsymbol{P}^1}$$

or, in more details,

$$\underbrace{\begin{bmatrix} \boldsymbol{p}^0 \\ 1 \end{bmatrix}}_{\boldsymbol{P}^0} = \boxed{\begin{bmatrix} x_p^0 \\ y_p^0 \\ z_p^0 \\ 1 \end{bmatrix} = \begin{bmatrix} (x_1^0)_x & (y_1^0)_x & (z_1^0)_x & (o_1^0)_x \\ (x_1^0)_y & (y_1^0)_y & (z_1^0)_y & (o_1^0)_y \\ (x_1^0)_z & (y_1^0)_z & (z_1^0)_z & (o_1^0)_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_p^1 \\ y_p^1 \\ z_p^1 \\ 1 \end{bmatrix}} = \underbrace{\begin{bmatrix} \boldsymbol{R}_1^0 & \boldsymbol{o}_1^0 \\ 0_{1\times 3} & 1 \end{bmatrix}}_{\boldsymbol{H}_1^0} \underbrace{\begin{bmatrix} \boldsymbol{p}^1 \\ 1 \end{bmatrix}}_{\boldsymbol{P}^1}$$

Representing Positions & Orientations





$$^{B}\boldsymbol{R}_{K} = \begin{pmatrix} ^{B}\boldsymbol{e}_{xK} & ^{B}\boldsymbol{e}_{yK} & ^{B}\boldsymbol{e}_{zK} \end{pmatrix} = \begin{pmatrix} u_x & v_x & w_x \\ u_y & v_y & w_y \\ u_z & v_z & w_z \end{pmatrix}$$

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

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

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

(This is called R the rotational Submatrix)

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

D vector is the position of the origin of the remote space in Local Coordinate dimensions

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Exercise

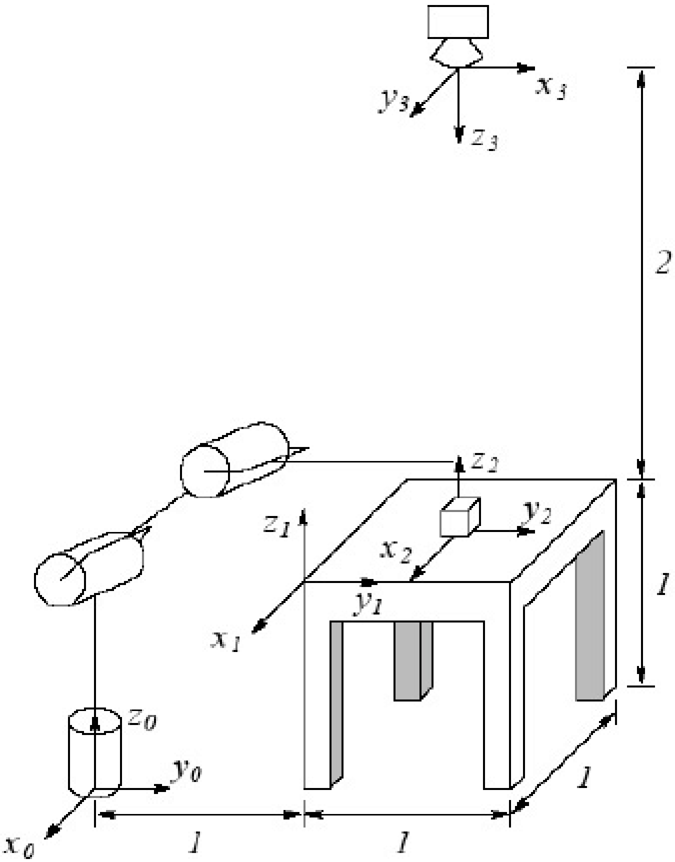

Figure 2.14: Diagram for Problem 2-39.

A cube measuring 200mm on a side is placed in the center of 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.

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