ROBOT KINEMATICS, MODELLING AND SIMULATION

ROBOTICS 2023

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DENMARK

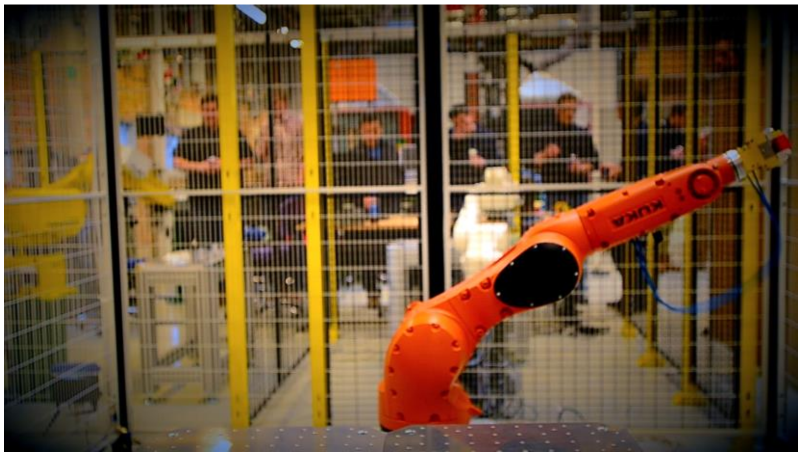
Fra studieordningen

VIDEN
- Grundlæggende aspekter i forbindelse med **robot kinematik**
- Metoder rumlig beskrivelse af objekter
- Grundlæggende metoder til kinematisk modellering af robotmanipulatorer
- Principper for kinematisk robotsimulering
- Omdannelse af bevægelser i opgaverum til robotbevægelser

FÆRDIGHEDER
- Anvendelse af homogene transformationsmatricer til at repræsentere position og orientering af objekter
- Beskrive den direkte og inverse kinematik af en robot
- Design enkle baneplanlæggere, herunder kartesiske og fælles interpolatorer
- Programmer en industrirobot til at udføre forskellige produktionsopgaver
- Omdanne beskrivelser i opgaverum til robotbevægelser
- Simulere den kinematiske opførsel af en robot

KOMPETENCER
- Skal kunne programmere en robot, så den ønskede kinematiske adfærd opnås
- Skal kunne simulere robottens kinematik
- Skal kunne løse enkle produktionsopgaver med en industrirobot

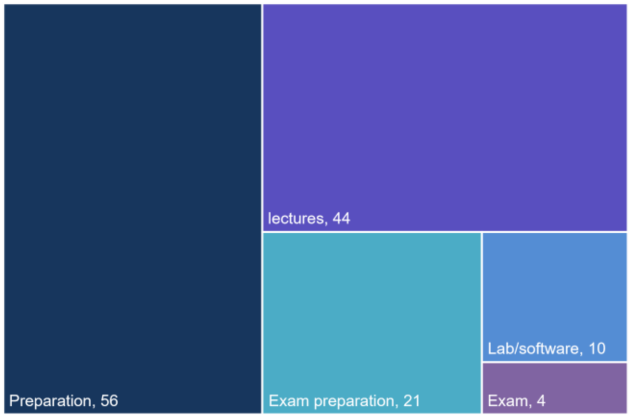
Not only modelling - You are going to work with real robots !!



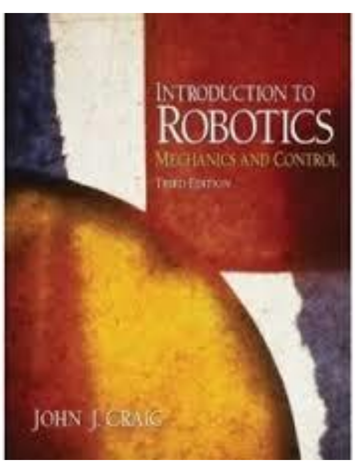
Lecture plan

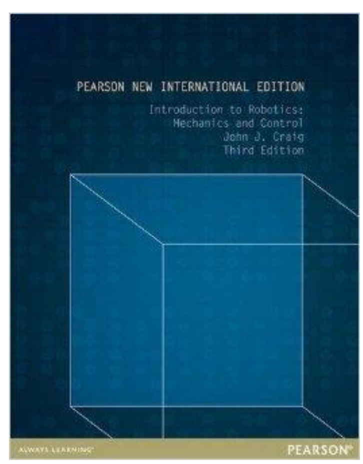
No	Responsible	Contents
1	Ole Madsen	Introduction to: • the course; • robotics and robot terminology.
2	Ole Madsen	Spatial descriptions and transformation matrices
3 (FIB)	Ole Madsen + More	Practical exercise with the on-line programming (1.5 timer/gruppe).
4	Ole Madsen	Orientation
5	Ole Madsen	Forward Kinematics I
6	Ole Madsen	Forward Kinematics II (go though 6 DOF robot) – exercise, you go though your robot
7	Ole Madsen	Inverse kinematics I
8	Ole Madsen	Inverse kinematics II (go through 6DOF robot) – you start on your robot
9	Ole Madsen	Trajectory generation and control (joint)
10	Ole Madsen	Trajectory generation and control (cartesian)
11	Ole Madsen	Jacobian/Exam preparation

Course workload 5 ECTS (135 hours)



The book





BASIC ROBOTIC BOOK
(WE USE CHAPTER 1,2,3,4,5,7,12)
(OTHER CHAPTERS ON ROB3)

But first make sure you have installed …

- Matlab:
  - Install newest MATLAB version
    - ***Mandatory MATLAB toolboxes***
      - Instrument Control Toolbox (To achieve robot connectivity)
      - Symbolic Math Toolbox
  - **To learn: https://se.mathworks.com/help/matlab/getting-started-with-matlab.html**
    - **Desktop Basic**
    - **Programming and Scripts**
- Install P**eter Corkes Robotics Toolbox for MatLab** :
  - link: https://petercorke.com/toolboxes/robotics-toolbox/
  - Download and run RTB10.4.mltbx
- ROBODK:
  - Install newest version of ROBODK (https://robodk.com/download)
  - License file found on Moodle
  - **To learn: run tutorial**

Agenda

- Introduction to robotics
- Some robot terminology
- Robot components
- Robot typologies
- Selecting an industrial robot arm

WHAT IS A ROBOT ?

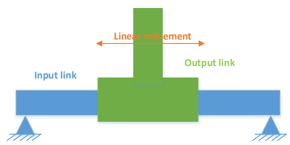
An Industrial robot is:

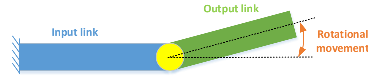
- properly not the most optimal employee since it is:
  - Stupid
  - Blind
  - One-armed

A robot is:

- An actuated **mechanism programmable** in two or more **axes** with a degree of **autonomy moving** within its environment, to perform intended tasks.

- Axis:
  - Direction used to specify the robot motion in a **linear** or **rotary** mode.



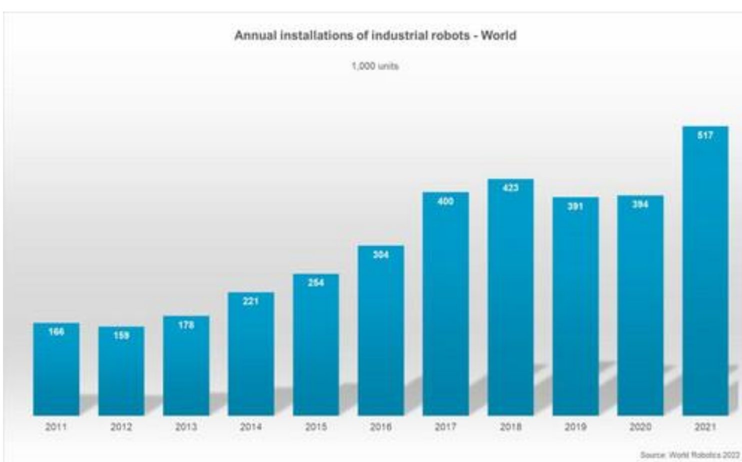


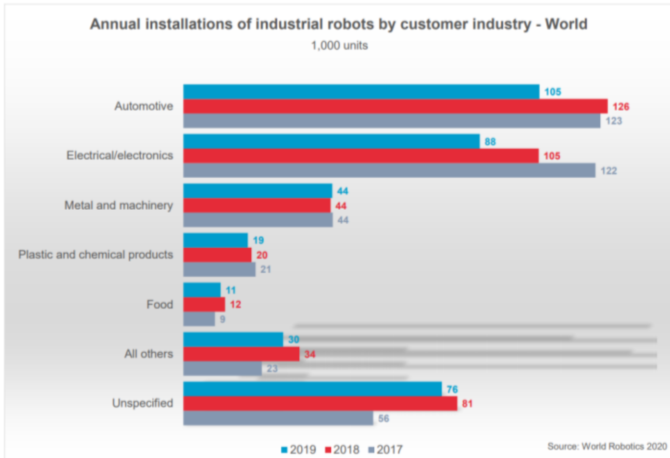
DS/ISO 8373 (1. EDITION 2013-06-04)
MANIPULATING INDUSTRIAL ROBOTS - VOCABULARY

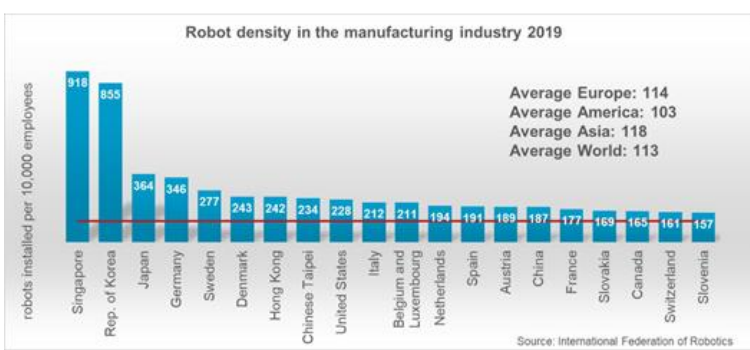
Industrial robots vs service robots

Industrial robots
- Work in relatively stable and structured environments
- Limited mobility
- Relative simple control programs
- Work inside fences

Service robots
- Work in the “real” world
- Are mobile
- Require a high degree of autonomy and intelligence
- Co-exists and collaborate with humans


Annual installations of industrial robots - World
1,000 units
166
159
178
221
254
304
400
423
391
394
517
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Source: World Robotics 2022


Annual installations of industrial robots by customer industry - World
1,000 units
Automotive
105
126
123
Electrical/electronics
88
105
122
Metal and machinery
44
44
44
Plastic and chemical products
19
20
21
Food
11
12
9
All others
30
34
23
Unspecified
76
81
56
2019 2018 2017
Source: World Robotics 2020


Robot density in the manufacturing industry 2019
robots installed per 10,000 employees
Average Europe: 114
Average America: 103
Average Asia: 118
Average World: 113
Singapore 918
Rep. of Korea 855
Japan 364
Germany 346
Sweden 277
Denmark 243
Hong Kong 242
Chinese Taipei 234
United States 228
Italy 212
Belgium and Luxembourg 211
Netherlands 194
Spain 191
Austria 189
China 187
France 177
Slovakia 169
Canada 165
Switzerland 161
Slovenia 157
Source: International Federation of Robotics

Why automate ?

- Reduce costs
- Improve working environment:
  - Remove dangerous jobs
  - Eliminate repetitive jobs
- Improve product quality
- Reduce through-put time
- Carry out processes and features that cannot be made manual

Why use robots for automation ?

- Robot based solutions are more flexible than traditional automation:
  - Kinematic flexibility
  - Fast change over to new products
  - (flexible capacity)

Why not automate ?

- High initial cost.
- Time to implement.

- The product life cycle is short.
- The products are highly customized.
- There are large variation in demands.

- The task is too technical difficult to automate. E.g:.
  - Problems with physical access to the work location,
  - Part location is unstructured
  - Adjustments required in the tasks
  - Manual dexterity requirements
  - Demands on hand eye coordination.

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Challenges for you $$$$$$$

- Reducing installation costs
- Improving flexibility – it takes time to reinstruct a robot for a new task.
- Improving capabilities – there are many tasks that robots cannot efficiently solve
- Improving abilities to adapt to changes in the environment
- Find a way to fire a robot if there is no use for it !!

Agenda

- Introduction to robotics
- **Some robot terminology**
- Robot components
- Robot typologies
- Selecting an industrial robot

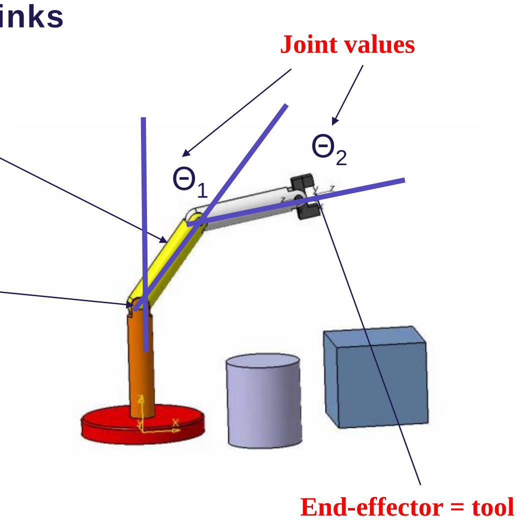
Joints axes and links

Link:

Rigid body connecting neighboring joints

Joint axes:

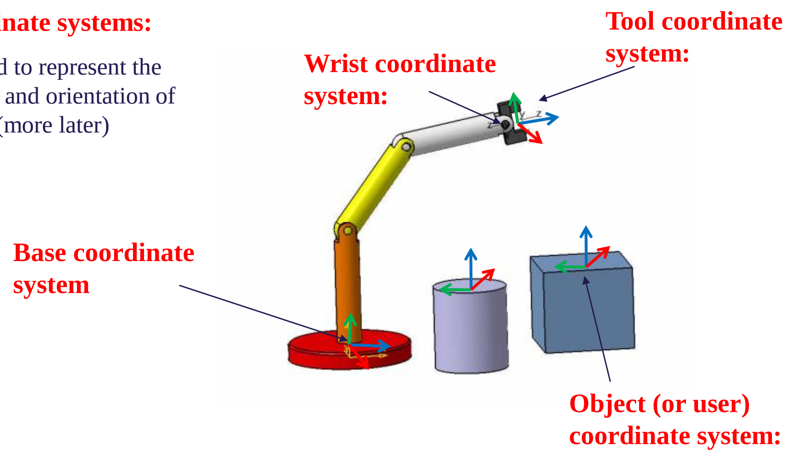
Directions used to specify the motion in a linear or rotary mode



Coordinate systems

Coordinate systems:

Are used to represent the position and orientation of objects (more later)



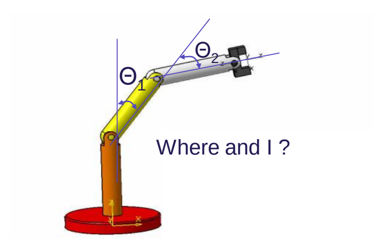
Forward and inverse kinematics

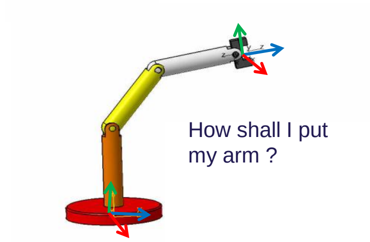
Forward kinematics:

- Θ_1 and Θ_2 are known
- Compute the location of the tool

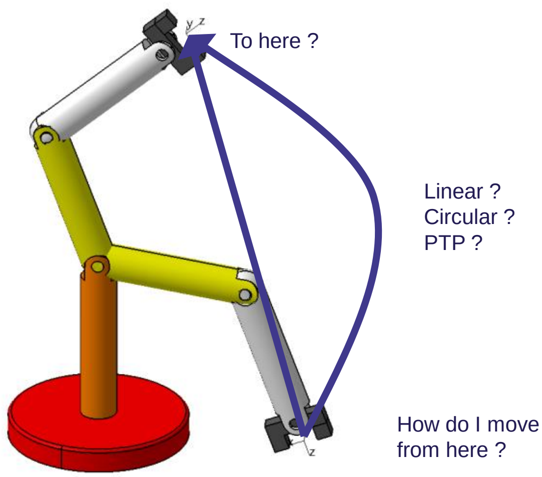
Inverse kinematics:

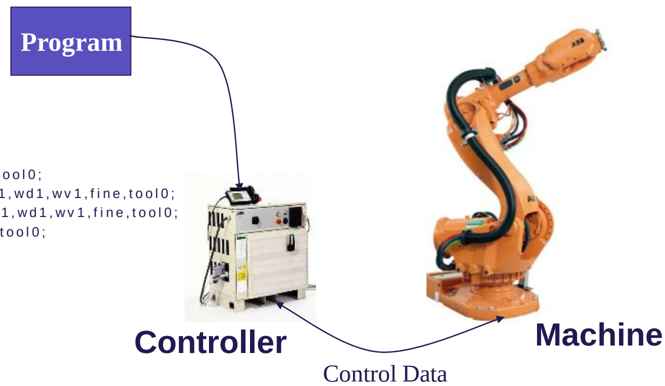
- The location of the tool is known.
- Compute Θ_1 and Θ_2





Trajectories






```
MODULE SVEJS
PROC main()
    MoveJ,*,v100,z50,tool0;
    ArcL\On,*,v200,sm1,wd1,wv1,fine,tool0;
    ArcL\Off,*,v100,sm1,wd1,wv1,fine,tool0;
    MoveL,*,v200,fine,tool0;
  ENDPROC
ENDMODULE
```

Agenda

- Introduction
- Some robot terminology
- **Robot components**
- Robot typologies
- Robot programs and programming

A Robot System (a robot cell)

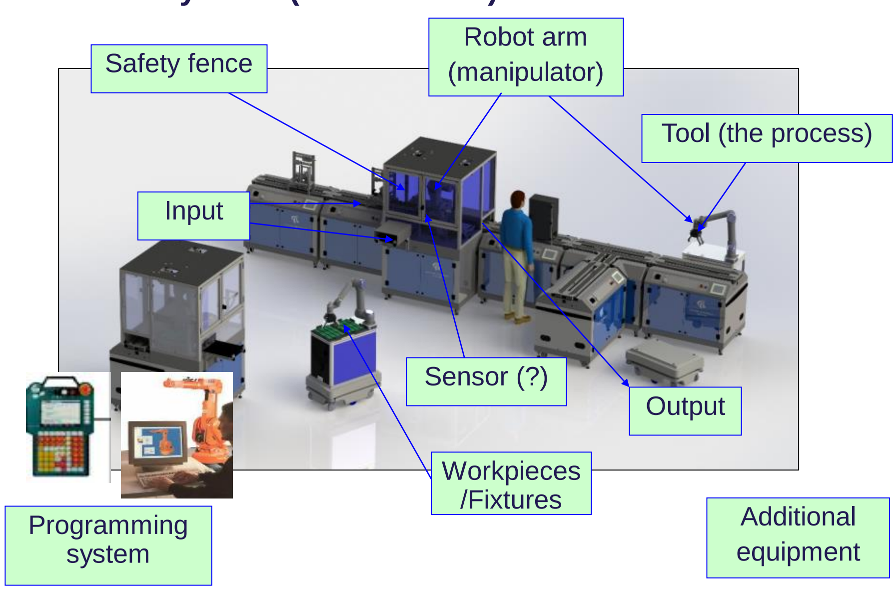


ABB program

```
%%%
  VERSION:1
  LANGUAGE:ENGLISH
%%%

MODULE SVEJS
  PERS weavedata wv1:=[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0];
  PERS welddata wd1:=[4,4,9,0,0,0];
  PERS seamdata sm1:=[0,0,0,0,0,0];

  PROC main()
    MoveJ [[309.73,-125.76,509.36],[0.246344,-0.692778,0.62777,-0.255495],[-1,0,-2,0],
[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]],v100,z50,tool0;
    ArcL\On,[[382.56,48.51,429.57],[0.242483,-0.704985,0.62782,-0.223698],[0,-1,-1,0],
[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]],v200,sm1,wd1,wv1,fine,tool0;
    ArcL\Off,[[388.2,109.07,429.57],[0.242508,-0.70503,0.627762,-0.223692],[0,-1,-1,0],
[9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]],v100,sm1,wd1,wv1,fine,tool0;
    MoveL [[298.77,-104.68,534.41],[0.246333,-0.692792,0.627756,-0.255505],[-1,0,-
2,0], [9E+09,9E+09,9E+09,9E+09,9E+09,9E+09]],v200,fine,tool0;
  ENDPROC
ENDMODULE
```

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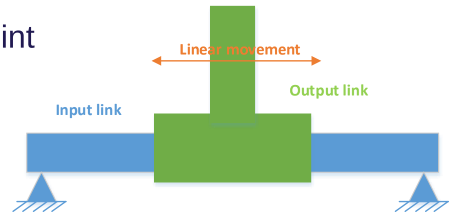
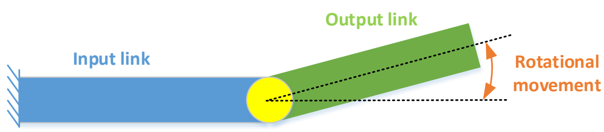
Joint types

Translational joint



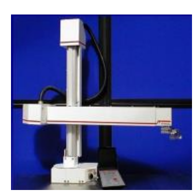
Rotational joint



Kinematic configuration


RRRRRR


TTT


RTT

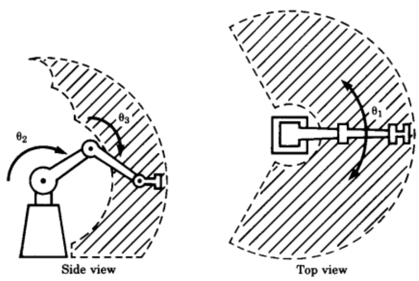

RRT


RRR


SCARA:RRTR

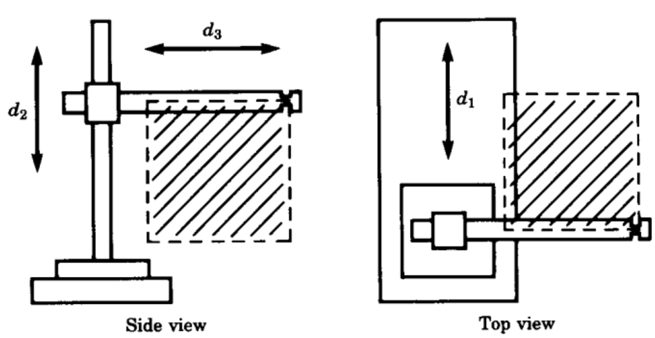
Articulated (anthropomorphic) (RRR)

- Two shoulder joints (vertical + horizontal elevation) and an elbow joint parallel to the elevation joint.



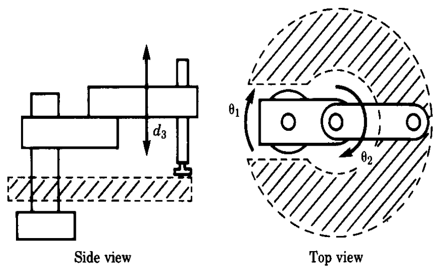
Cartesian (gantry) robot (TTT)

- Three perpendicular translational axes.
- Stiff structures allow construction of large robots



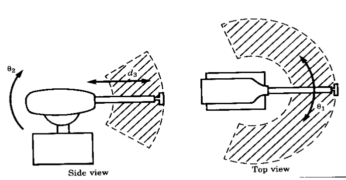
Scara (RRTR)

- Three revolute parallel joints allowing it to move and orient in plane.
- Usually very fast robots.
- Well suited to pick and place.

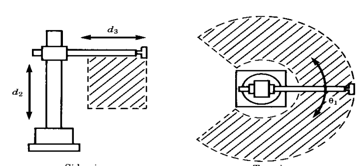


More configurations

Spherical (RRT)

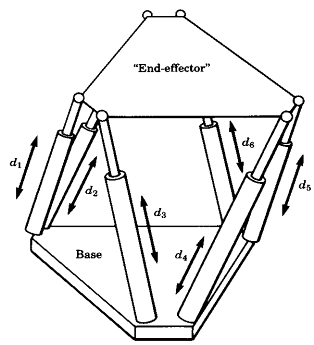


Cylindrical (RTT)



Closed structures

- Increased stiffness
- Fast and/or strong robots
- Reduced allowable range of motion



Flexpicker

Agenda

- Introduction to robotics
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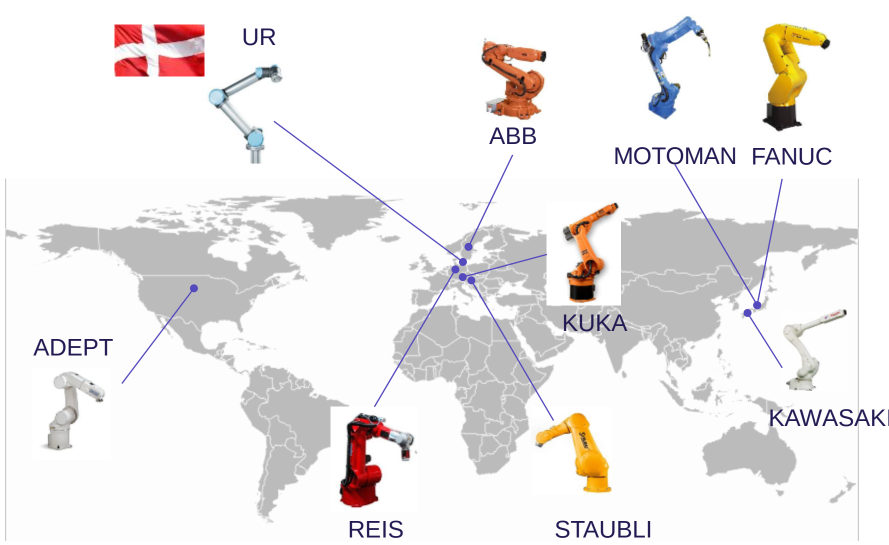
- Robot typologies
- **Selecting an industrial robot arm**



KUKA-robots

KUKA

KR 3 R540

Technical data

Maximum reach	541 mm
Maximum payload	3 kg
Pose repeatability (ISO 9283)	± 0.02 mm
Number of axes	6
Mounting position	Floor; Ceiling; Wall
Footprint	179 mm x 179 mm
Weight	approx. 26.5 kg

Axis data

Motion range	
A1	±170 °
A2	-170 ° / 50 °
A3	-110 ° / 155 °
A4	±175 °
A5	±120 °
A6	±350 °

Operating conditions

Ambient temperature during operation	5 °C to 45 °C (278 K to 318 K)

Protection rating

Protection rating (IEC 60529)	IP40
Protection rating, in-line wrist (IEC 60529)	IP40

Controller

Controller	KR C4 compact

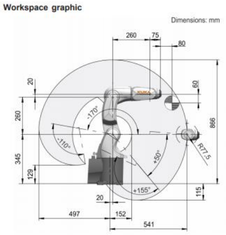
Teach pendant

Teach pendant	KUKA smartPAD

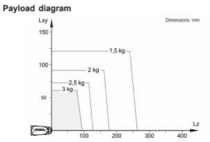
Cycle time

167 cycles per minute (25 mm / 305 mm / 25 mm, 1 kg)

Workspace graphic

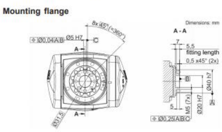


Payload diagram

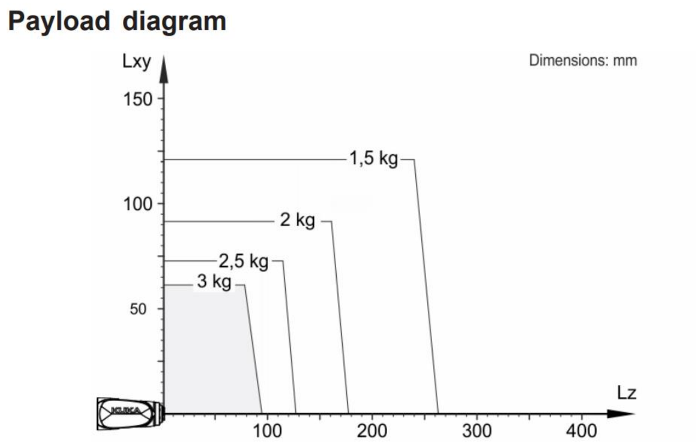


The KR 3 R540 is designed for a rated payload of 2 kg in order to optimize the dynamic performance of the robot. With reduced load center distances, higher loads up to the maximum payload may be used. The specific load case must be verified using KUKA.Load. For further consultation, please contact KUKA Support.

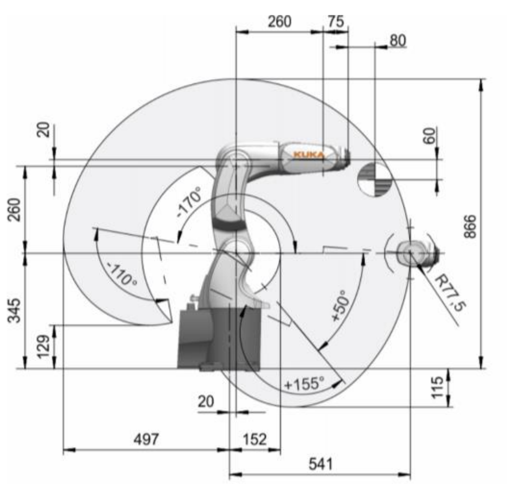
Mounting flange



Payload



Working envelope/reach



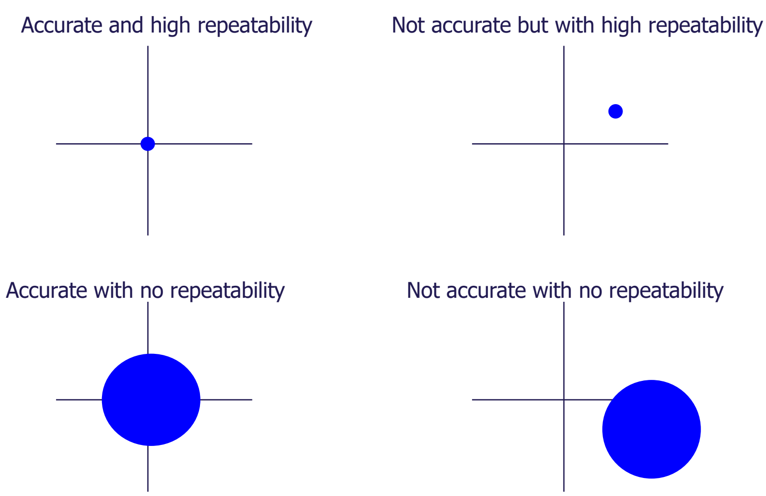
FOR KUKA HOME PAGE

Robot Accuracy and Repeatability

Two terms used to define precision in robotics:

1. Accuracy - capability to position the robot's wrist at a desired location in the work space
2. Repeatability - capability to position the wrist at a previously taught location in the work space

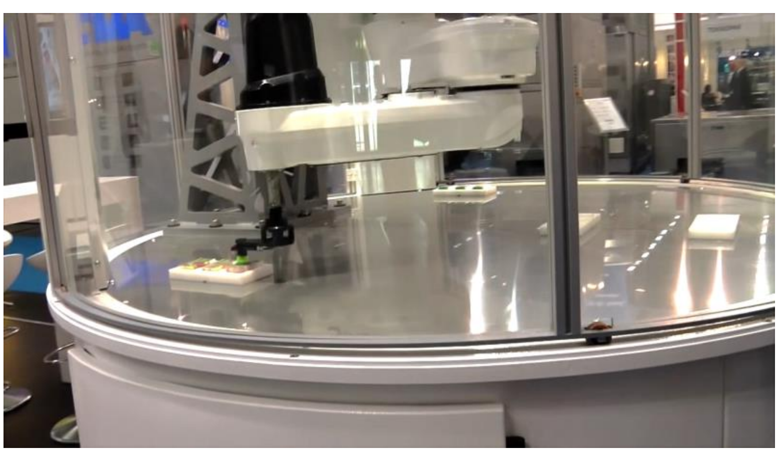
Robot Accuracy and Repeatability



Speed/Cycle time

- Max. speed
  - Axis 1 150°/s
  - Axis 2 150°/s
  - Axis 3 150°/s
  - Axis 4 360°/s
  - Axis 5 360°/s
  - Axis 6 450°/s

- Cycle time: 138 cycles/min (25/305/25; 1 kg Payload)



IP rating

- IP ratings designate the degree of protection an enclosure provides against the ingress or intrusion of foreign objects.
- IP ratings consist of the letters "IP" followed by two numbers:
  - The first number designates protection against solid objects.
  - The second number designates protection against water.

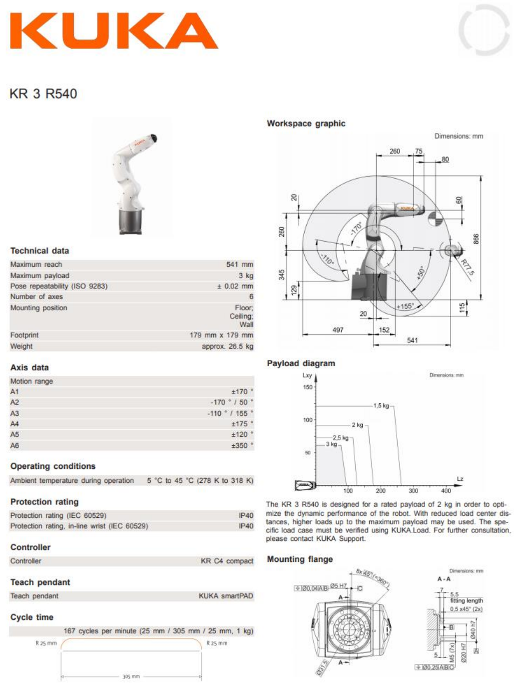
IP Rating	Solid Object Size
IP1X	$\geq$ 50mm (1.97") diameter
IP2X	$\geq$ 12.5mm (0.49") diameter
IP3X	$\geq$ 2.5mm (0.098") diameter
IP4X	$\geq$ 1.0mm (0.039") diameter
IP5X	dust-protected
IP6X	dust-tight

IP Rating	Type of Water
IPX1	vertical dripping
IPX2	dripping (up to 15° tilt)
IPX3	spraying (up to 60° angle)
IPX4	splashing from any direction
IPX5	jets from any direction
IPX6	powerful jets from any direction
IPX7	temporary immersion
IPX8	continuous immersion

Collaborative or traditional ??

ISO/TS 15066:2016

Force limited



KUKA

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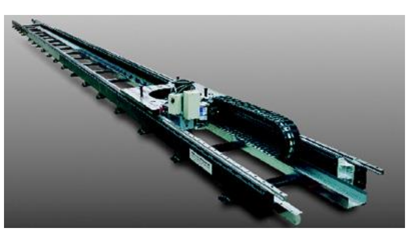
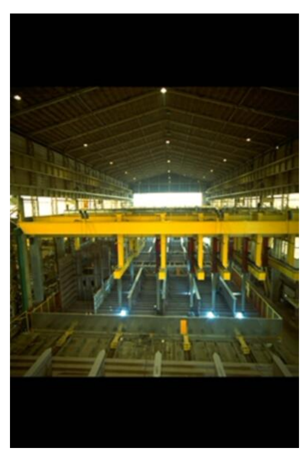
Mounting flange

Number of joint axes

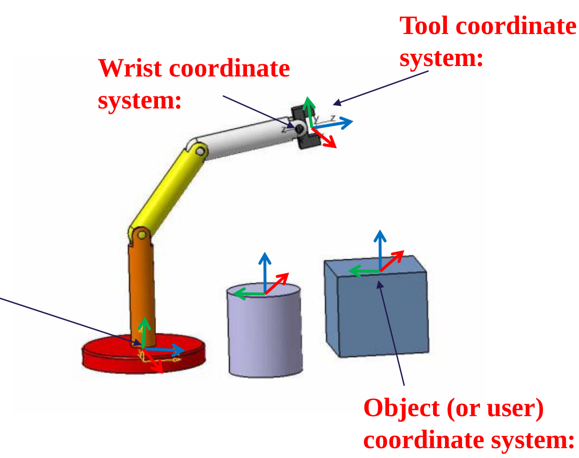




Next time:

Coordinate systems:

Are used to represent the position and orientation of objects (more later)



Lecture plan

No	Responsible	Contents
1	Ole Madsen	Introduction to: • the course; • robotics and robot terminology.
2	Ole Madsen	Spatial descriptions and transformation matrices
3 (FIB)	Ole Madsen + More	Practical exercise with the on-line programming (1.5 timer/gruppe).
4	Ole Madsen	Orientation
5	Ole Madsen	Forward Kinematics I
6	Ole Madsen	Forward Kinematics II (go though 6 DOF robot) – exercise, you go though your robot
7	Ole Madsen	Inverse kinematics I
8	Ole Madsen	Inverse kinematics II (go through 6DOF robot) – you start on your robot
9	Ole Madsen	Trajectory generation and control (joint)
10	Ole Madsen	Trajectory generation and control (cartesian)
11	Ole Madsen	Jacobian/Exam preparation

Exercise:

1. Discuss:
   a) How do we represent robot locations ?
   b) What is forward kinematics ?
   c) What is inverse kinematics ?
   d) What is a robot trajectory ?

2. Investigate various robots:
   a) Find data sheets for:
      - KR6 700sixx (KUKA)
      - UR 5 (Universal robot)
      - Adept Cobra 800 (Omron/Adept)
   b) Identify the joint axes and the links of the robots
   c) Identify the robot topology
   d) Compare the robots (workspace, payload, speed, weight..)

Hand-in solutions for 1.2 on Moodle

3. ROBODK
   a) Install RoboDK
   b) Run the tutorial

4. MATLAB
   a) Familiarize yourself with the programming environment (making m-files)
   b) Install Corkes: Robotic toolbox

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