Hochschule Karlsruhe
University of
Applied Sciences

Industrial Robot Laboratory

Level 1 & Level 2

Version: 1.0

Author: Prof. Dr.-Ing. Björn Hein, Prof. Dr.-Ing. Christian Wurll

Date: Winter semester 2021 - 2022

Short Bio

Prof. Dr.-Ing. habil. Björn Hein

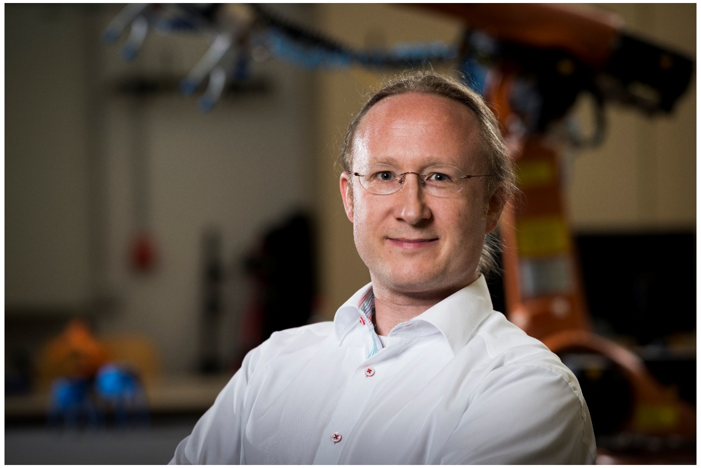
2018 – today **University of Applied Sciences Karlsruhe**
Prof. for Intelligent Production
Topic: Cloud-Production and Robotics

2012 – 2018 **Karlsruhe Institute of Technology (KIT)**
Shared Professorship: SCHUNK and KIT
Topic: Robot Interaction Technologies

2003 – 2012 **Karlsruhe Institute of Technology (KIT)**
Research Group-Leader and **Habilitation Thesis in 2010**: Model-based Online-Programming Techniques for Industrial Robots

1999 – 2003 **University of Karlsruhe (TH)**
Inst. for Process Control & Robotics
Ph.D. Thesis: Automatic Offline-Programming of Industrial Robots

1992 – 1998 **University of Karlsruhe (TH)**
Study of Electrical Engineering
Control Theory and Robotics



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Industrial Robotics Laboratory

Content of the course:

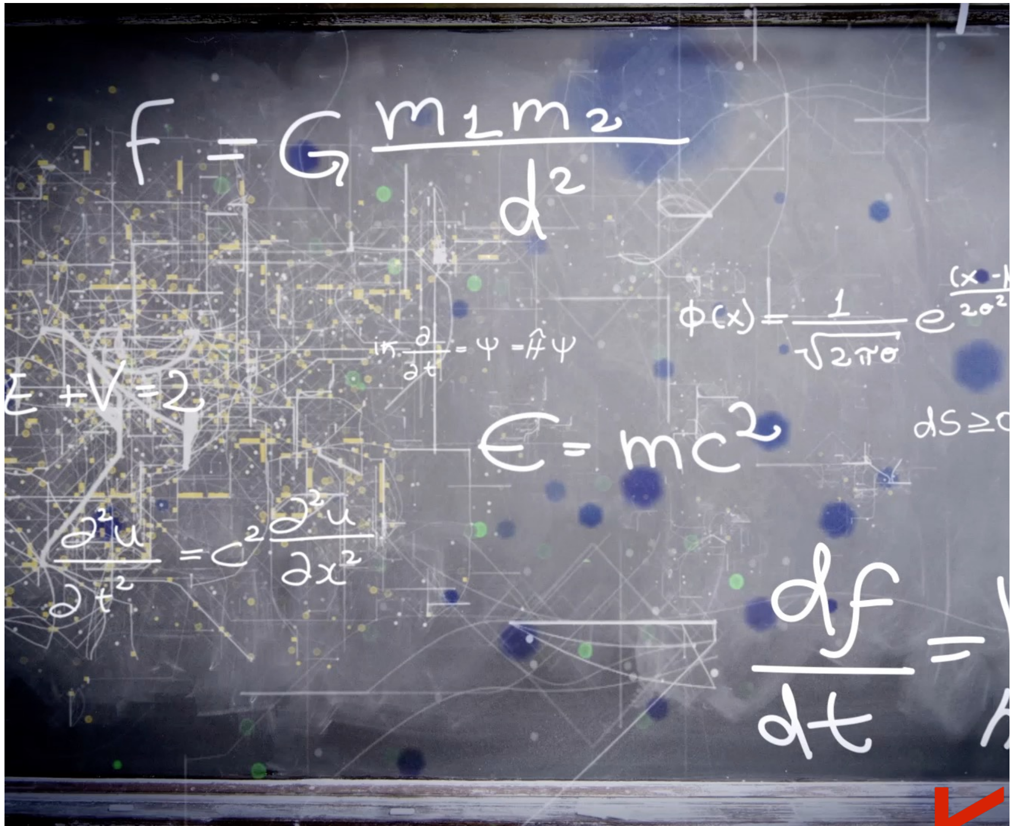
+ General structure and components of a robot controller
+ Fundamentals regarding kinematics, movement commands, coordinate systems
+ Basic programming techniques and IO-handling
+ Application: object handling
+ Project: Solving a given task by programming in KRL (KUKA-Robot-Language) and using all functionality and skill-sets acquired during the course.

Learning objectives

+ Understanding a robot controller and its essential components /functionalities
+ Understanding and using movement commands and kinematics
+ Understanding and using expert programming techniques
+ Understanding and using robot programs for solving automation tasks
+ Analyzing and assessing robot programs and movement commands

Literature

- J.J. Craig: "Introduction to Robotics", Addison-Wesley, Third Edition, 2009.
- R. Dillmann, M. Huck: "Informationsverarbeitung in der Robotik", Springer-Verlag Berlin, Heidelberg, 1991
- J. Herzberg: "Mobile Robots", Springer Vieweg, 2012
- Siciliano, Bruno, Khatib, Oussama (Eds.): "Springer Handbook of Robotics", 2nd Edition, Springer, 2016.
- R.P. Paul: "Robot Manipulators: Mathematics, Programming, and Control", The MIT Press, Cambridge/MA, 1981.
- W. Weber: "Industrieroboter", Fachbuchverlag Leipzig, Carl Hanser Verlag Munich Vienna, 2007



Industrial Robotics Lab

Learning unit 2: Introduction to Robotics

Version: 1.0

Author: Prof. Dr.-Ing. Björn Hein, Prof. Dr.-Ing. Christian Wurll

Date: 25.10.2021

Introduction to Robotics: Definition of Terms

+ The term "robot" has its origin in the Slavic word "robota", which in its sense means hard work.

+ Internationally, there is a certain confusion of terms, since similar systems such as manipulators or insertion devices are counted among robots and are often counted and added in statistics.

Industrial Robots

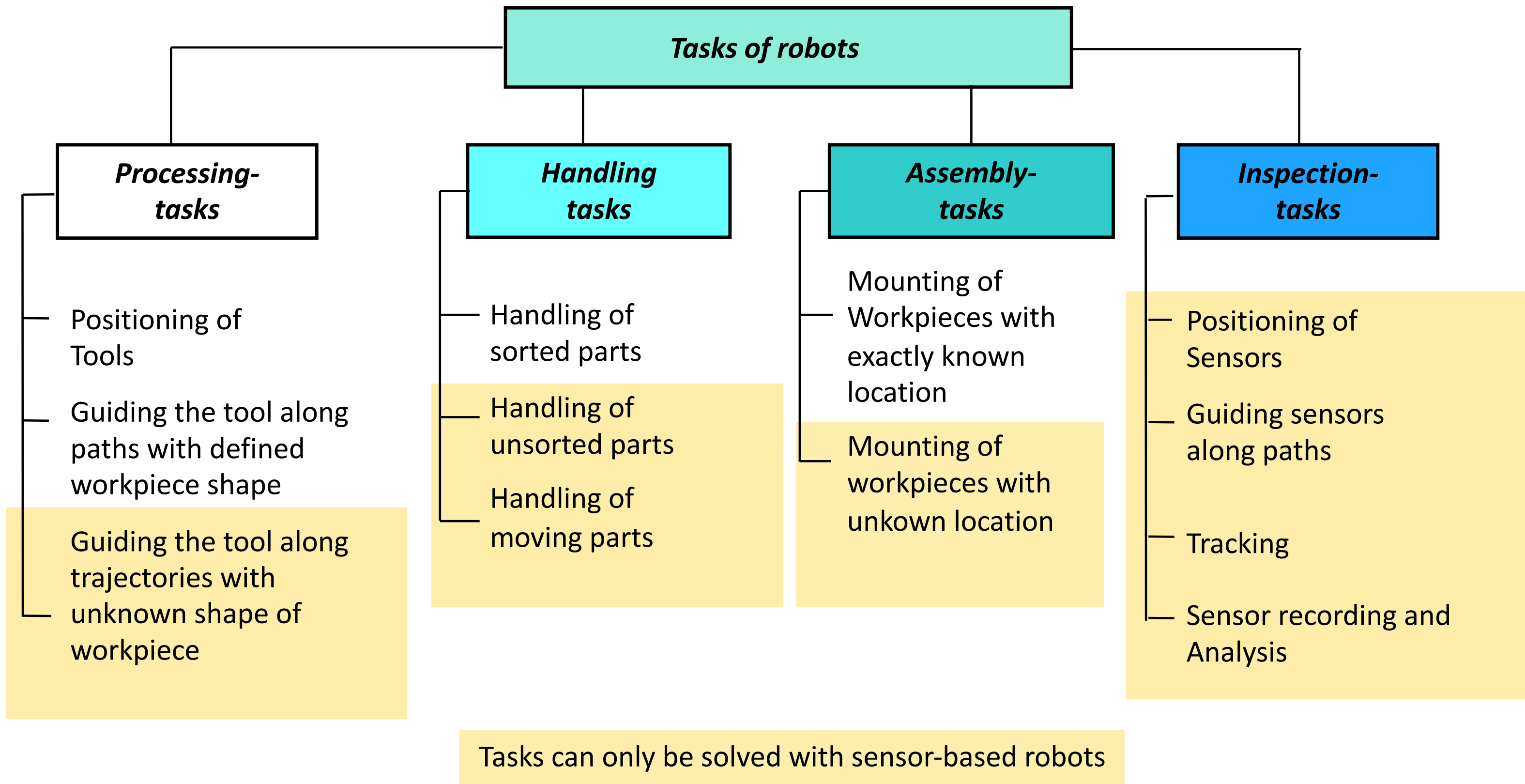
Characteristics

+ Preprogrammed sequences and movements
+ Sensor guided manipulation
+ Structured environment
+ Single, timed, repetitive tasks

Industrial Robots (ISO)

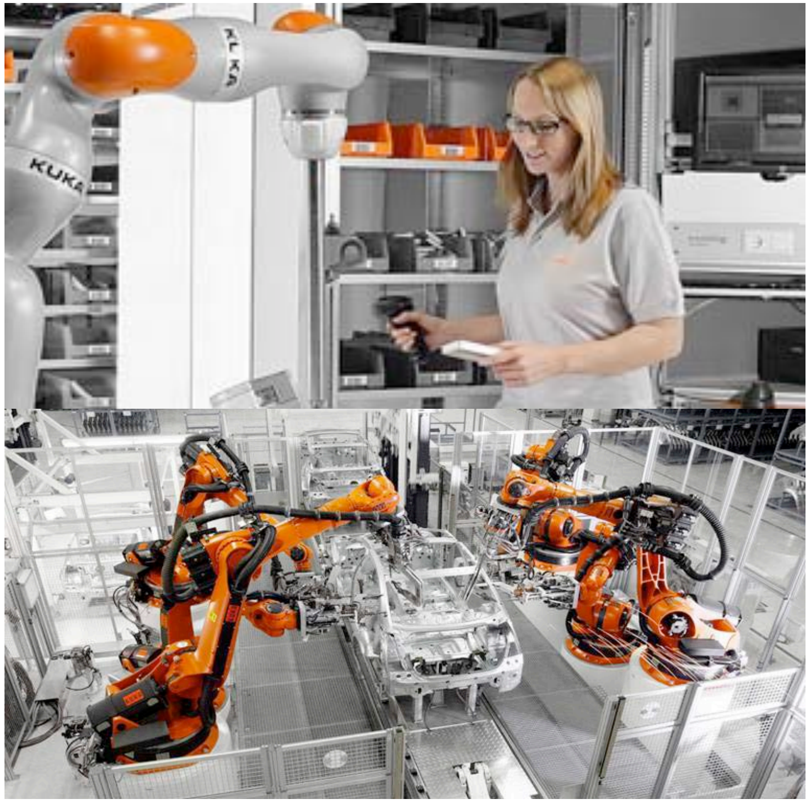
+ Automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications

Typical Robotic Tasks



Industrial Robots

+ As a freely programmable handling device in various forms.
+ It is characterized by flexibility, the ability to work in complex spatial arrangements and on defined paths.
+ The so-called system always consists of a kinematic chain with a fixed part and one or more arms.
+ There is always a tool at the end of the chain, such as a gripper or a welding torch



Quelle: KUKA

Global Players

Different Fields of Applications

- **Six-axis robots** in almost all dimensions with different payloads, ranges and in a wide variety of variants
- **HRC-capable lightweight robots** for direct cooperation between man and machine
- Heat and dirt resistant robots for **extreme environmental conditions**
- Industrial robots in clean room variants for **high hygiene requirements**
- Small robots in **waterproof design,** for example for use in **machining tools**
- Special handling robots with **enormous reach** for loading and unloading large parts, e.g. in **press linkage**
- Palletizing robots for **handling tasks of** all kinds
- Welding robots designed for accuracy and **maximum mobility**
- Console robots in all versions for special types of reachability demands
- High-precision robots for **maximum precision**
- Mobile robots and mobile platforms for the **next evolutionary stage of** flexibility of industrial production

Interdisciplinary of Robotics

Robotics has relationships with the following disciplines:

+ Computer Science
+ Electrical engineering (e.g. hardware, sensors, actuators)
+ Mechanical engineering (mechanical structure)
+ Mathematics
+ Artificial intelligence (image recognition, speech recognition, learning, multi-agent systems, planning, ...)
+ Cognitive Science
+ Psychology
+ Biology (human, animal behavior)

„Robotics Laws“

The most important aspect in robotics is human safety.

To this end, Isaac Asimov proposed the three laws of robotics, which are as follows:

1) A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2) A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Terms - Kinematics, Axes and Dynamics

+ The ***kinematics*** describes the mechanical structure of the robot, i.e. the spatial relation of the axes according to their order and type. It deals with the geometry and the time-dependent aspects of the movement. In kinematics, all dynamic aspects are abstracted/neglected.

+ The individual links of an industrial robot are connected via linear and rotational joints to form a ***kinematic chain.*** The links, joints and their drives/motors form the ***axes of the robot***.

+ The ***main axes are*** used to position the end effector, i.e. the tool or workpiece, in space.

+ The ***hand or auxiliary axes*** are primarily responsible for the orientation of the tool and therefore usually consist of a series of rotational joints.

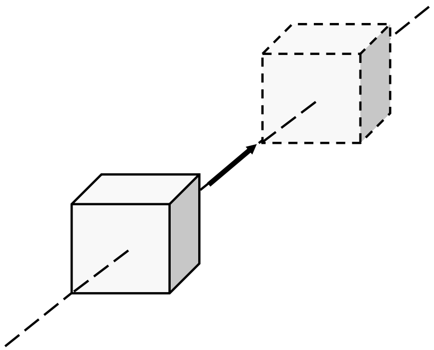
+ ***Dynamics*** is concerned with the consideration of forces (acceleration force, inertia force, gravity force, Coriolis force, friction force) acting on the robot components.

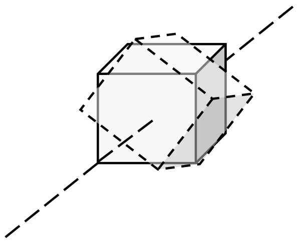
Spatial Axis - Joints

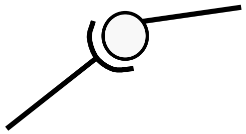
+ Straight line in space
+ Body can move along spatial axes: *Translation*
+ Body can rotate around spatial axes: *Rotation*

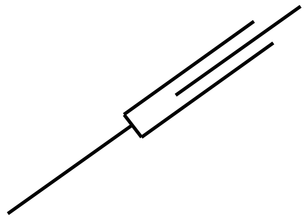
Mechanical component that has a

+ rotating joint (hinge joint) or a
+ translational (prismatic joint) of one body (link) against another



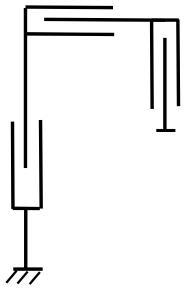




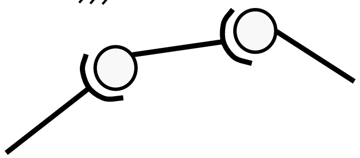


Kinematics

- Arrangement of axes → Kinematic chain
- Serial kinematics
  - gantry robot

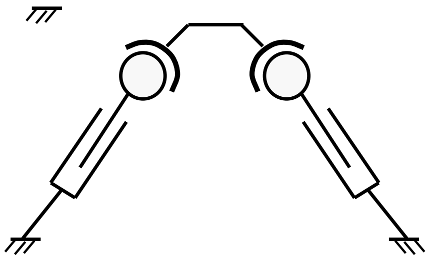


  - articulated robot



The joints are arranged in series and form an open kinematic chain

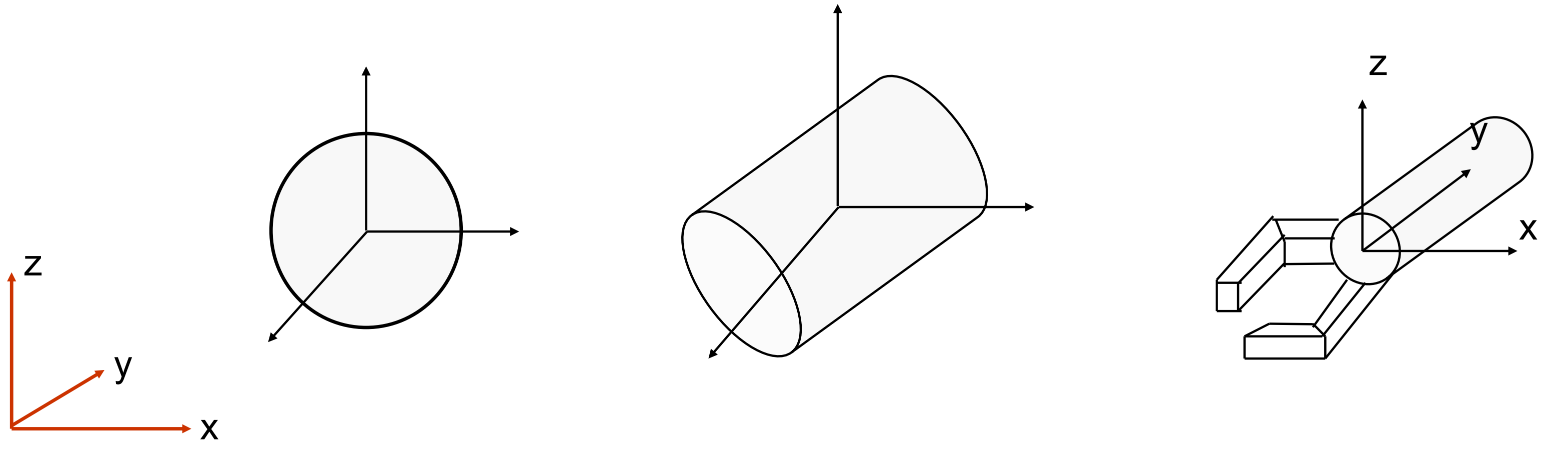
- Parallel kinematics



The joints are arranged parallel and form a closed kinematic chain

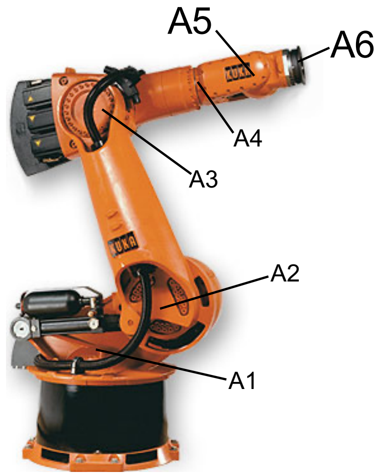
Degrees of Freedom (Space. / Body)

+ 1 Degree of Freedom = 1 translation or 1 rotation
+ A body has max. 6 degrees of freedom in space
  (3 translations + 3 rotations)



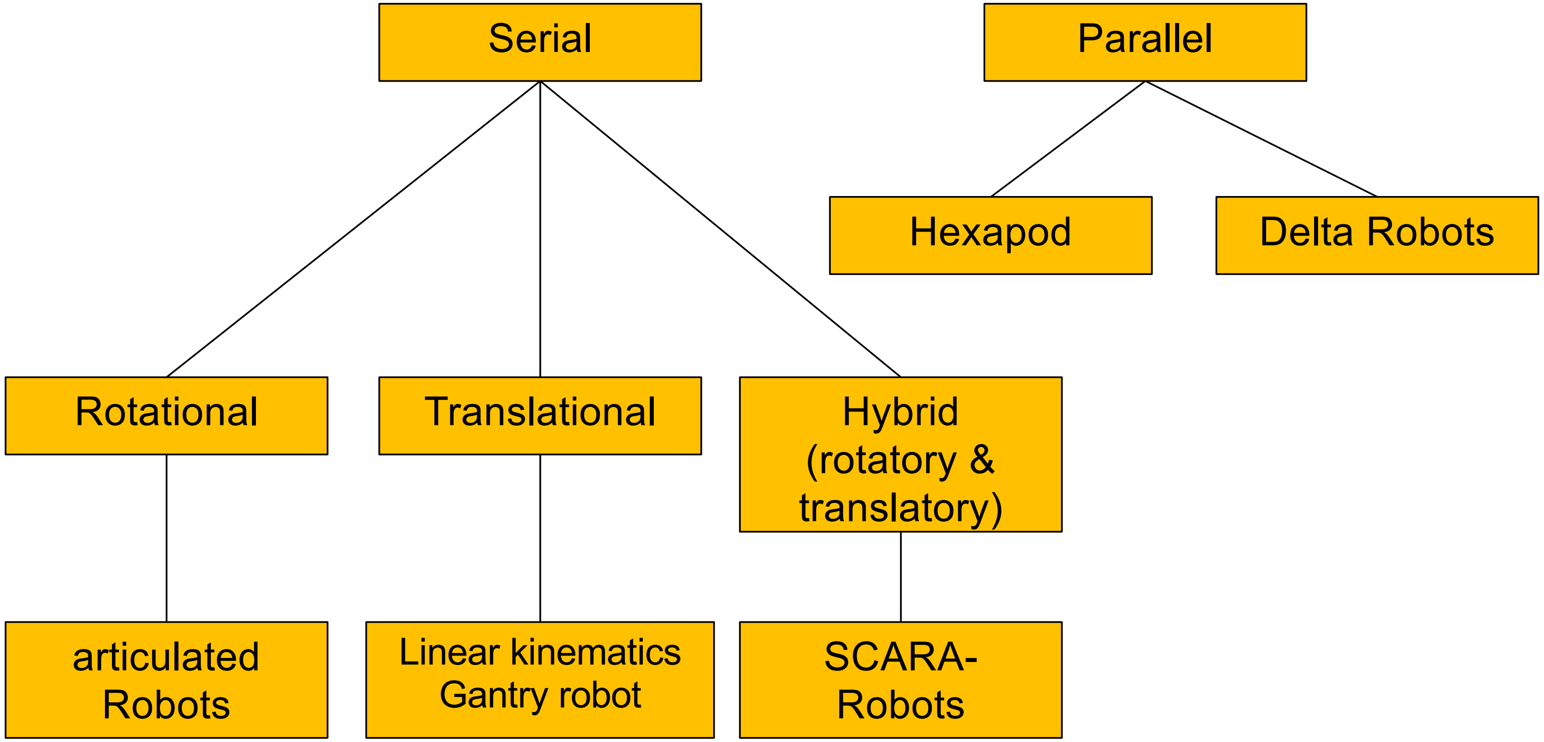
Degrees of Freedom (motion)

- 1 degree of freedom = 1 joint
- All degrees of freedom of motion spawn the *configuration space*

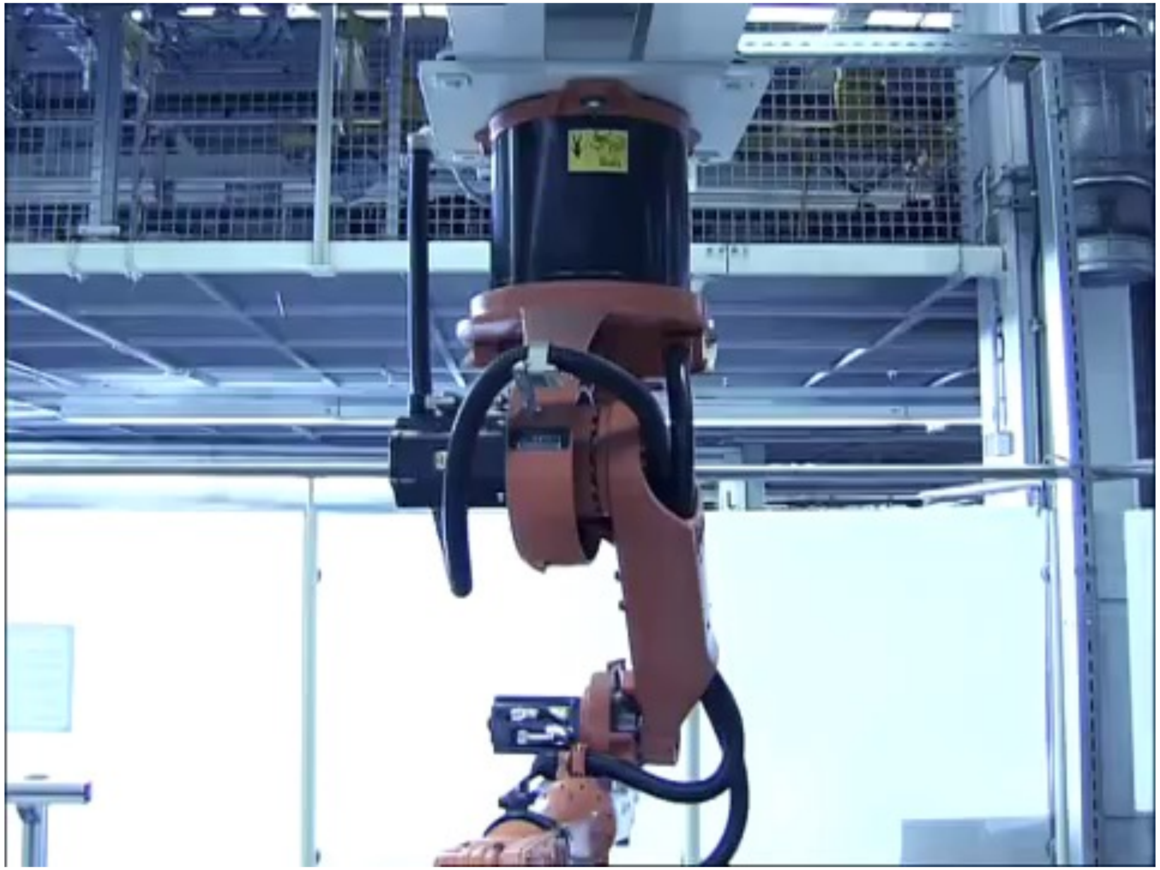


- *redundancy:*
  - No. of degrees of freedom of movement
  - No. of degrees of freedom

Kinematics Types



Examples: Automotive Sector



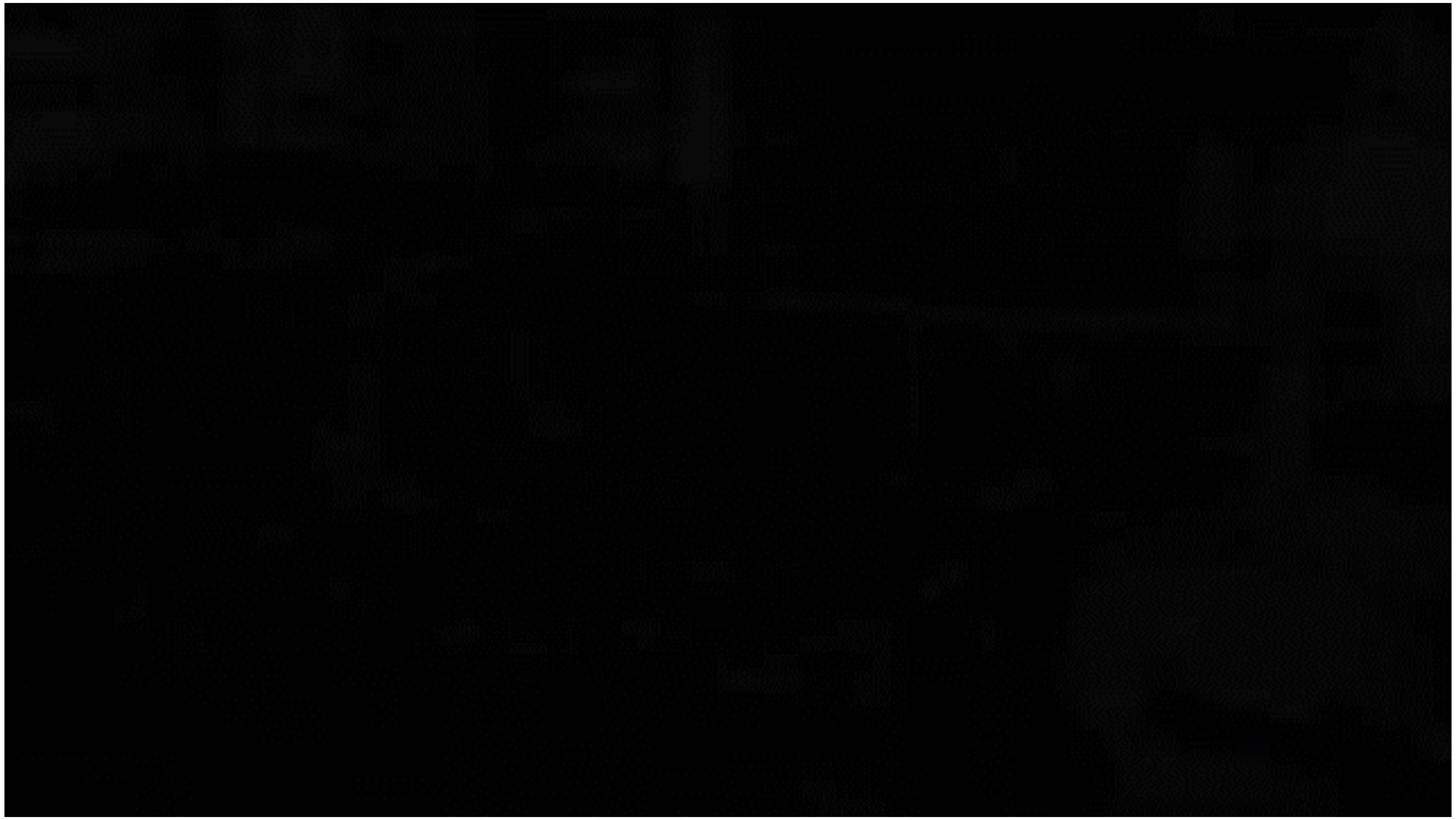
Example: Food Industry

Example: Palletizing in Food Industry

Example: Robots in Wood Working

Example: Food Handling

Example: Meat Cutting



Example: Glueing

Example: Electronics

Example: Entertainment

Example: Medical Applications - CyberKnife

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Tutorial 3: Design and function of a KUKA Robot System

Version: 1.0

Author: Prof. Dr.-Ing. Björn Hein, Prof. Dr.-Ing. Christian Wurll

Date: 25.10.2021

3 Structure and Function of a KUKA Robot System

1 Control system (control cabinet (V)KR C4)

2 Manipulator (robot mechanics)

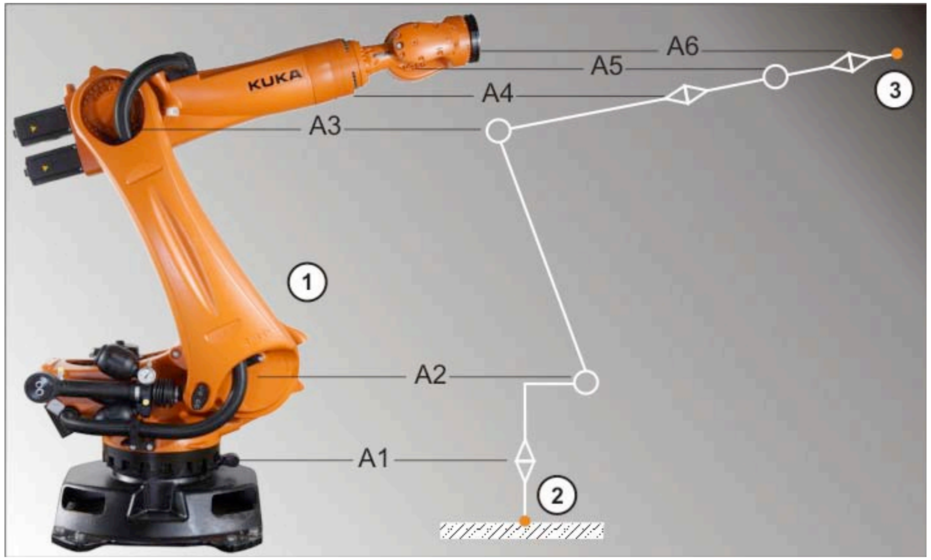
3 Operating and programming handheld device (KUKA smartPAD)

Periphery - everything that is outside the system boundaries.

+ Tools (Effector/Tool)
+ Safety devices
+ Conveyor belts
+ Sensors
+ Machines
+ etc.

3 Structure and function of a KUKA Robot System - Manipulator

- The manipulator has 6 axes.
- The beginning of the kinematic chain is at the robot base (ROBROOT)
- The free end of the kinematic chain is the flange (FLANGE)
- The movement takes place via servo motors in the robot mechanics



3 Structure and Function of a KUKA Robot System - Overview of components Robot mechanics

The components of a robot mechanism are mainly made of cast aluminum and steel.

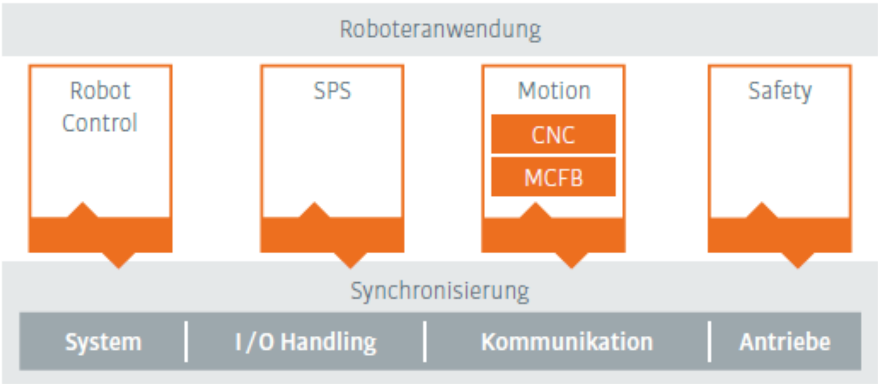
In isolated cases, carbon fiber components are also used.

The individual components are numbered from the bottom (foot of the robot) to the top (flange of the robot):

1. Base frame
2. Carousel
3. Counterbalance
4. Swing arm
5. Arm
6. Hand

3 Design and function of a KUKA robot system - Controller

+ The robot is controlled via the KR C4 control cabinet.
+ The KR C4 integrates robot control, PLC control, motion control (e.g. KUKA.CNC) and safety control in its software architecture.

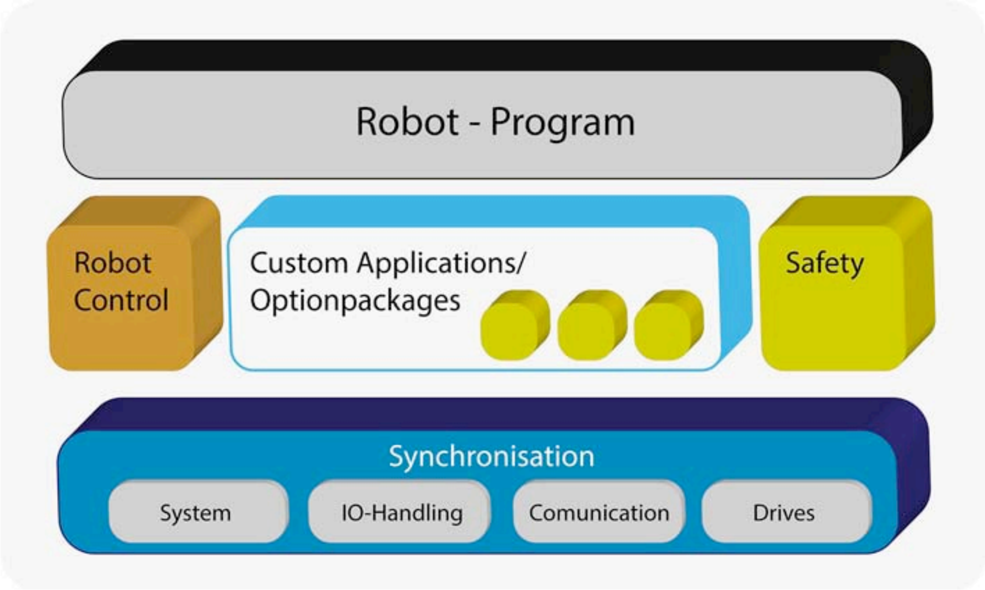


3 Design and Function of a KUKA Robot System - Controller

- The **KR C4 controller** can control up to **six robot axes**, plus up to **three or six external axes.**

3 Design and Function of a KUKA robot system - Controller

+ KR C4-based controllers operate according to a modular concept on the control side.
+ The **KPC-KUKA** *PC* plays a central role here.
+ Robot programs access the necessary hardware interfaces via applications corresponding to the task.
+ In addition to the always available **system-relevant applications** (e.g. Safety, Robot Control, etc.), the control system can also be supplemented by **customer-specific applications** (e.g. PLC, XM, Process Control, etc.).



3 Structure and Function of a KUKA robot system - Communication

Communication options via bus systems (e.g. ProfiNet, Ethernet IP, Interbus, etc.)

+ Programmable logic controllers (PLC)
+ More controls
+ Sensors and actuators

Communication options via network

+ Master computer
+ More controls
+ Service notebook

Industrial Robotics Lab

Learning unit 4: Robot Operation and Cell Safety

Version: 1.0
Author: Prof. Dr.-Ing. Björn Hein, Prof. Dr.-Ing. Christian Wurll
Date: 25.10.2021

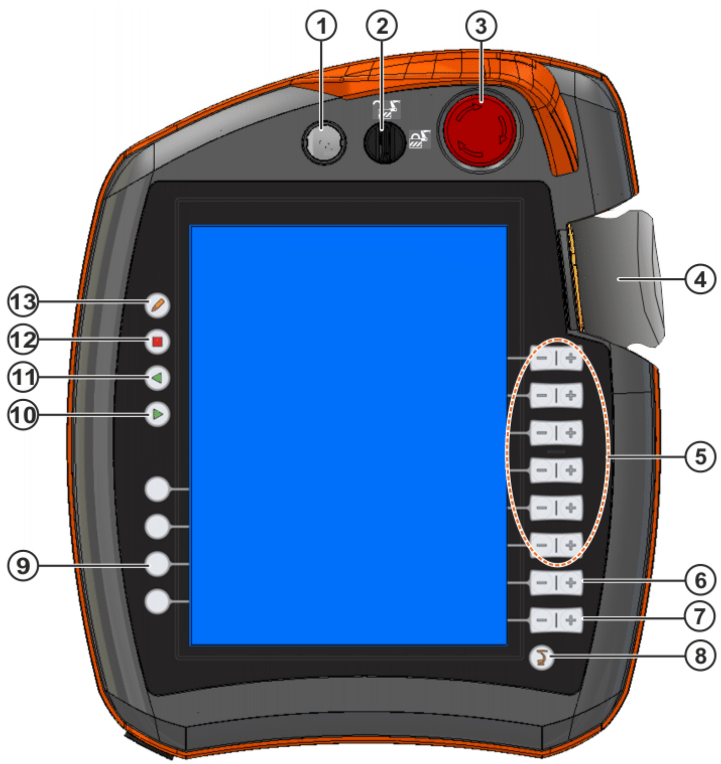
4 Robot Operation and Cell Safety: The intelligent KUKA smartPAD

All relevant machine & program functions are controlled via the smartPad:

+ Moving the robot by hand (6D mouse)
+ Switching between the operating mode
+ various safety devices
+ Creating, editing programs

4 Robot Operation and Cell Safety: the intelligent KUKA smartPAD

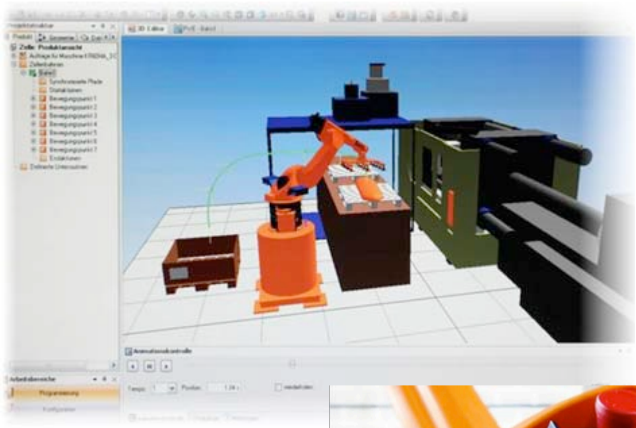
1. Unplug key for the "smartPAD" requirements
2. Switch for selecting the operating mode
3. EMERGENCY STOP
4. 6D mouse for manual movement of the robot
5. Keys for manual movement of the robot
6. Button for setting the Program Overide (POV)
7. Key for setting the hand override (HOV)
8. Main menu button
9. Status keys for technology packages
10. Start button
11. Start-back button
12. STOP button
13. Keyboard key



4 Robot Operation and Cell Safety: Robot Programming

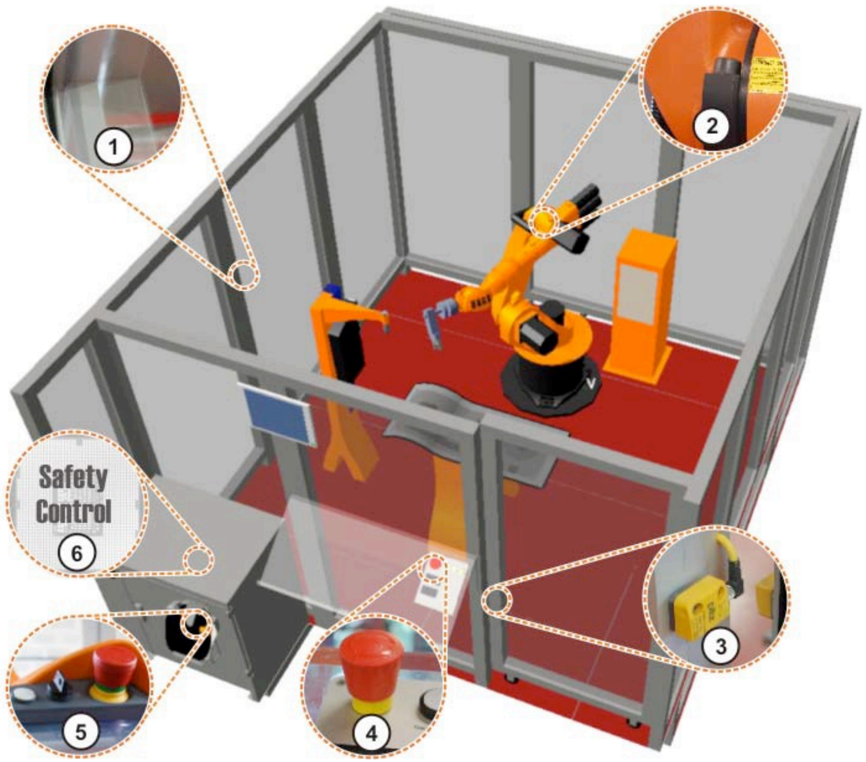
Various methods can be used to program the robot:

+ Online programming on the smartPAD
+ Offline programming on the operator PC incl. graphic simulation
+ Textual programming on the operator PC with KUKA OfficeLite



4 Robot Operation and Cell Safety: Cell Safety

1. Protective fence
2. Mechanical end stops or axis range limiters for axes 1, 2 an
3. Safety door with door contact for monitoring the closing fu
4. Emergency STOP button (external)
5. Emergency STOP button, enabling button, key switch for ca
6. Integrated (V)KR C4 safety controller



Industrial Robotics Lab

Unit 5: Working with the Navigator

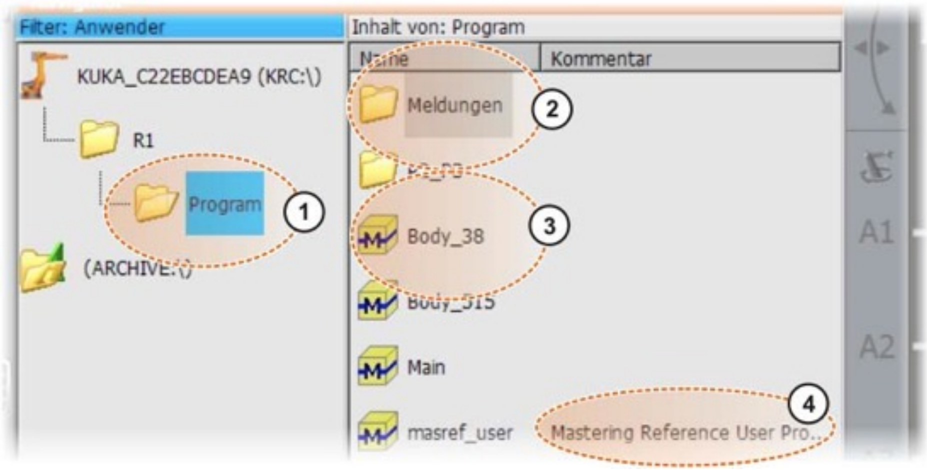
Version: 1.0

Author: Prof. Dr.-Ing. Björn Hein, Prof. Dr.-Ing. Christian Wurll

Date: 25.10.2021

5 Working with the Navigator

+ Program modules should always be placed in the Program folder.
+ Modules are marked by the symbol with the "M".
+ A module can be provided with a comment on the function description.



1 Main folder for programs

2 Subfolder for additional programs

3 Program module/module

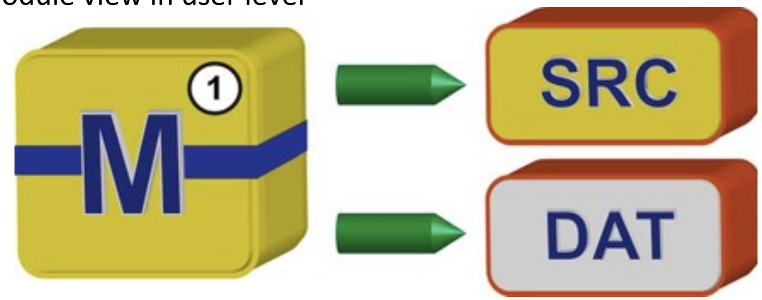
4 Comment of a program module

5 Working with the Navigator

+ A module always consists of **two parts**:

Module view in user level

Source file



DAT file

+ The SRC file contains the program code

```
DEF MAINPROGRAM()
INI
SPTP HOME Vel= 100% DEFAULT
SPTP P1 Vel=100% PDAT1 TOOL[1] BASE[2]
SPTP P2 Vel=100% PDAT2 TOOL[1] BASE[2]
…
END
```

+ The DAT file contains permanent data and point coordinates

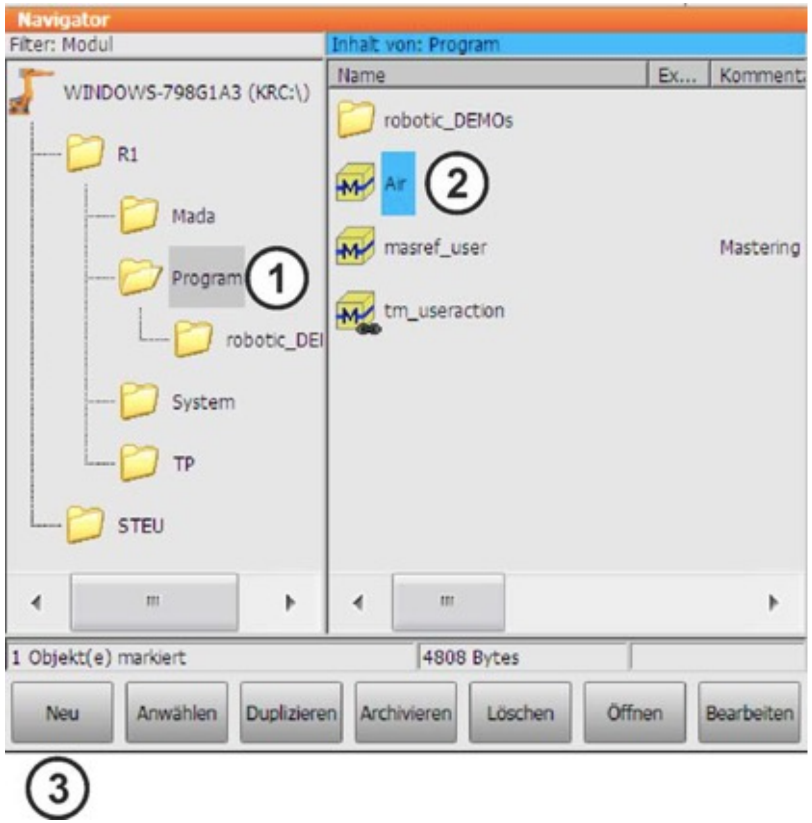
```
DEFDAT MAINPROGRAM()
DECL E6POS XP1={X 900, Y 0, Z 800, A 0, B 0, C 0, S 6, T 27, E1 0, E2
0, E3 0, E4 0, E5 0, E6 0}
DECL FDAT FPOINT1 …
…
ENDDAT
```

5 Working with the Navigator

You can also create your own modules.
(**1 Program 2** Focus on desired folder **3 New**)

Once a module has been created, it can be edited using the softkeys on the smartPAD

+ Duplicate/Copy
+ Delete
+ Rename (via **Edit** soft key)
+ Archive (via **Edit** soft key)
+ (After archiving also recovery from the archive).



5 Working with the Navigator

+ Robot programs are **selected** via the smartPAD ("Select" soft key)
+ To start a program, both Start forward **1** and Start reverse **2 are** available.
+ Reversing a program is only possible after passing through the INI line
+ The speed can be set in the program override POV

5 Working with the Navigator

+ The smartPAD always displays the current program status

Symbol	Farbe	Beschreibung
	grau	Kein Programm ist angewählt.
	gelb	Satzzeiger steht auf der ersten Zeile des angewählten Programms.
	grün	Programm ist angewählt und läuft ab.
	rot	Angewähltes und gestartetes Programm wurde angehalten.
	schwarz	Satzzeiger steht am Ende des angewählten Programms.

5 Working with the Navigator

+ **Structure of** a robot program:

```
 1 DEF KUKA_Prog()
 2
 3 INI
 4 SPTP HOME VEL= 100 % DEFAUL
 5 SPTP P1 VEL= 100 % PDAT1 To
 6 SPTP P2 VEL= 100 % PDAT1 To
 7 SLIN P3 VEL= 1 m/s CPDAT1 T
 8 SLIN P4 VEL= 1 m/s CPDAT2 T
 9 SPTP P5 VEL= 100% PDAT1 Too
10 SPTP HOME VEL= 100 % DEFAUL
11
12 END
```

```
DEF Programm()
---------------------
          1
---------------------
INI
---------------------
          2
---------------------
---------------------
          3
---------------------
END
```

Zeile	Beschreibung
1 und 12	**Nur in der Benutzergruppe Experte sichtbar:** ■ "DEF *Programmname()*" steht immer am Anfang eines Programmes ■ "END" beschreibt das Ende eines Programms
3	■ Die "INI"-Zeile beinhaltet Aufrufe von Standardparametern, die zur korrekten Abarbeitung des Programms notwendig sind. ■ Die "INI"-Zeile muss immer zuerst abgearbeitet werden!
4 bis 10	■ Eigentlicher Programmtext mit Bewegungsbefehlen, Warte-/Logikbefehlen etc. ■ Der Fahrbefehl "PTP Home" wird häufig am Anfang und am Ende eines Programms verwendet, da dies eine eindeutige und bekannte Position ist.

Bereich	Beschreibung
1	Deklarationsteil ■ Hier werden der Steuerung neue Daten mitgeteilt(z.B. Variablen angelegt)
2	Initialisierungsteil ■ Hier werden die Grundeinstellungen für das Roboterprogramm getätigt
3	Anweisungsteil ■ Im Anweisungsteil findet die eigentliche "Arbeit" statt! ■ Bewegungsprogrammierung ■ Logik ■ Daten werden geschrieben oder eingelesen

5 Working with the Navigator

An initialization run is always performed at the beginning of a program.

This is called SAK move („Satzkoinzidenz“)

An SAK move is also performed in the following cases:

+ Program selection
+ Program reset (reset)
+ Manual procedure during program operation
+ Change in the program
+ Selection of motion

Reasons for a SAK move:

+ A SAK move is necessary to establish a match between the current robot position and the coordinates of the current point in the robot program.
+ Only when the current robot position is equal to a programmed position, the path planning can take place. Therefore, the TCP must always be aligned with the path first.

5 Working with the Navigator - Messages

+ Various messages can appear on the robot controller, some of which stop the running program and can be acknowledged or not.

Tipps zum Umgang mit Meldungen:

- Bewusst lesen!
- Ältere Meldungen zuerst lesen. Eine neuere Meldung könnte eine Folge der Alten sein.
- Nicht einfach die Schaltfläche **"Alle OK"** drücken.
- Besonders nach dem Hochfahren: Meldungen durchsehen. Dabei alle Meldungen anzeigen lassen. Durch Drücken auf das Meldungsfenster expandiert die Meldungsliste.

Symbol	Typ
	Quittiermeldung ▪ Zur Darstellung von Zuständen, bei der zur weiteren Abarbeitung des Roboterprogrammes eine Bestätigung des Bedieners erforderlich ist (z. B. "Quit NOT-HALT"). ▪ Eine Quittiermeldung hat immer zur Folge, dass der Roboter anhält bzw. nicht startet.
	Zustandsmeldung ▪ Zustandsmeldungen melden aktuelle Zustände der Steuerung (z. B. "NOT-HALT"). ▪ Zustandsmeldungen sind nicht quittierbar, solange der Zustand ansteht.
	Hinweismeldung ▪ Hinweismeldungen geben Informationen zur korrekten Bedienung des Roboters (z. B. "Starttaste erforderlich"). ▪ Hinweismeldungen sind quittierbar. Sie müssen aber nicht quittiert werden, da das angewählte Roboterprogramm nicht angehalten wird, bzw. das Handverfahren des Roboters weiterhin möglich ist.
	Wartemeldung ▪ Wartemeldungen geben an, auf welches Ereignis (Zustand, Signal oder Zeit) die Steuerung wartet. ▪ Wartemeldungen können mit Drücken der Schaltfläche "Simuliere" manuell abgebrochen werden.

5 Working with the Navigator - Operating Modes

T1 (Manual Reduced Speed)

+ For test operation, programming and teaching
+ Speed in program mode max. 250 mm/s
+ Speed in manual mode max. 250 mm/s

T2 (Manual High Speed)

+ For test operation
+ Speed in program mode according to the programmed speed!
+ Manual jogging: not possible

AUT (Automatic)

+ For industrial robots without higher-level control
+ Speed in program mode according to the programmed speed!
+ Manual jogging via touch keys or space mouse not possible

AUT EXT (Automatic External)

+ For industrial robots with higher-level control (PLC)
+ Speed in program mode according to the programmed speed!
+ Manual jogging not possible