Lecture Robotics

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1700	J.D. Vancanson built music playing dolls
1805	H. Maillardet designed a picture painting doll
1946	G.C.Devol developed a controller which can store electrical signals, to use them later for the controlling of mechanical devices
1947	Patents for manipulation for the handling of radioactive materials
1952	Prototype of a NC-Mashine at MIT demonstrated
1954	C.W. Kenword received a patent for a 2-Arm-Robot
1959	First commercial robot (Planet Corporation)
1960	First Ultimate Robot (with hydraulic drive, numerical control) installed
1966	Tralfa developed and installed color spraying robot
1968	“Stakey”, a mobile robot is demonstrated at the Standard Research Institute
1971	First purely electrically actuated robot (Standford-Arm)
1973	Robot programming language - WAVE was developed
1975	First assembly operation by Olevettis SIGMA robots
1979	Development of SCARA robots at the Yamanashi university
1981	Direct Drive robot developed at the Carnegie Mellon University
1984	Several programming systems for development demonstrated
1985	World-wide development of mobile autonomous robots

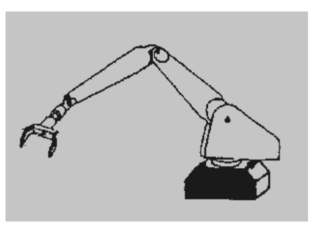
History of Robots

Robot

✧ Like humans
✧ Learning

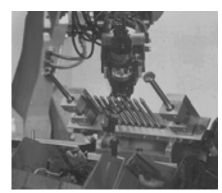
Industrial robot

✧ Universally substitutable
✧ Motion automata
✧ Freely programmable
✧ Handling/manipulation production task

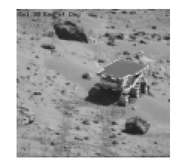


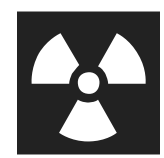
Robot and industrial robot in comparison

✧ Manufacturing, assembly technique



✧Aerospace
✧ Nuclear science
✧ Under water technique
✧ Service industry





Applications of Robot-technique

Autonomy of robot

by

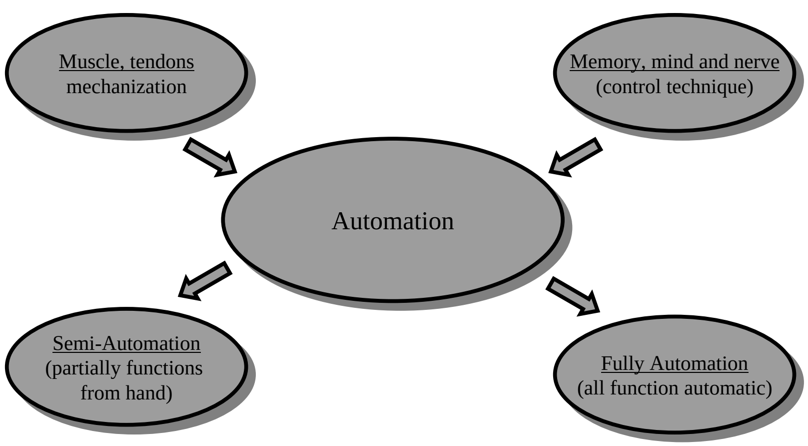
- ✧ Automatic planning
- ✧ Automatic control
- ✧ Supervision of performance
- ✧ Recognition of a conflict
- ✧ Deletion of errors

Autonomy of robot

Requirements leading to Flexible Production Techniques

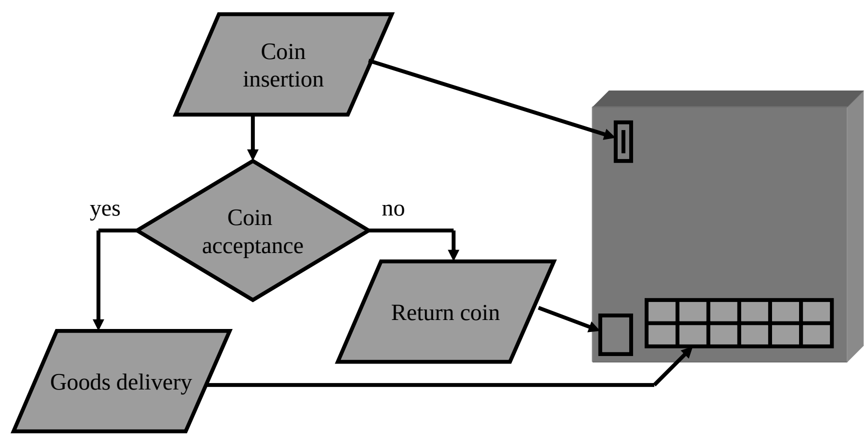
- ✧ Short delivery time
- ✧ Individuality of products
- ✧ High constant product quality
- ✧ Competitive prices

Changing of production basis to flexible production



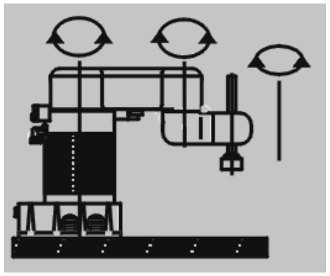
Human activity, mechanization and automation

An automatic machine is an artificial system, which autonomously follows a program.

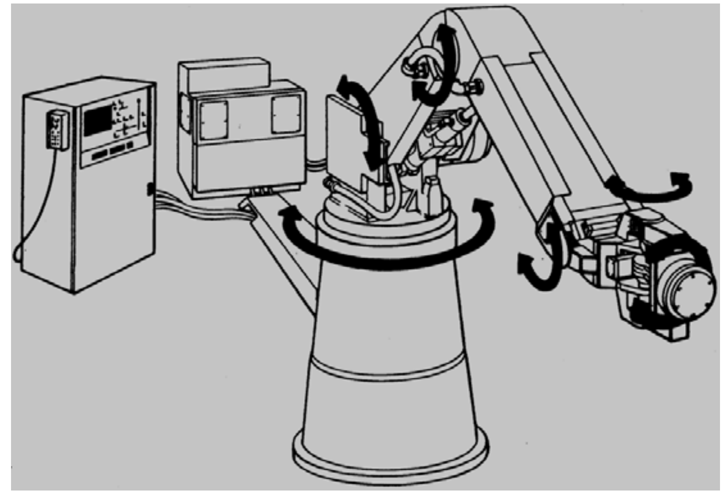


Definition of automatic machine

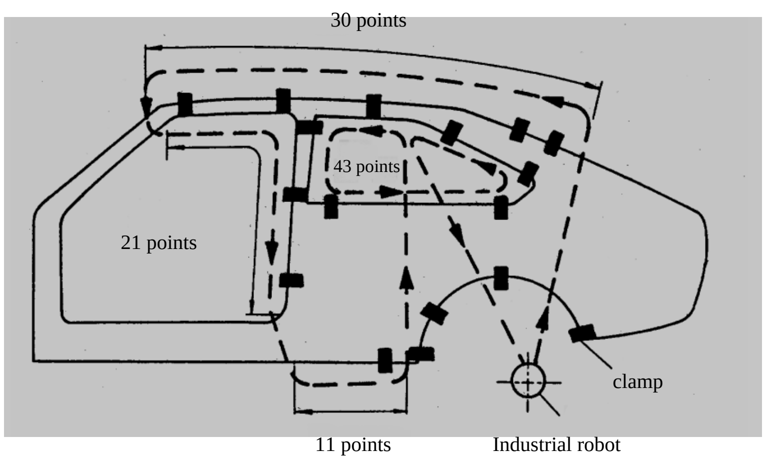
An **Industrial robot** is a multi-functional handling device,
which is free programmable in several axes
and is able to move workpieces, tools or special devices in such a way,
that a specific task will be executed properly.



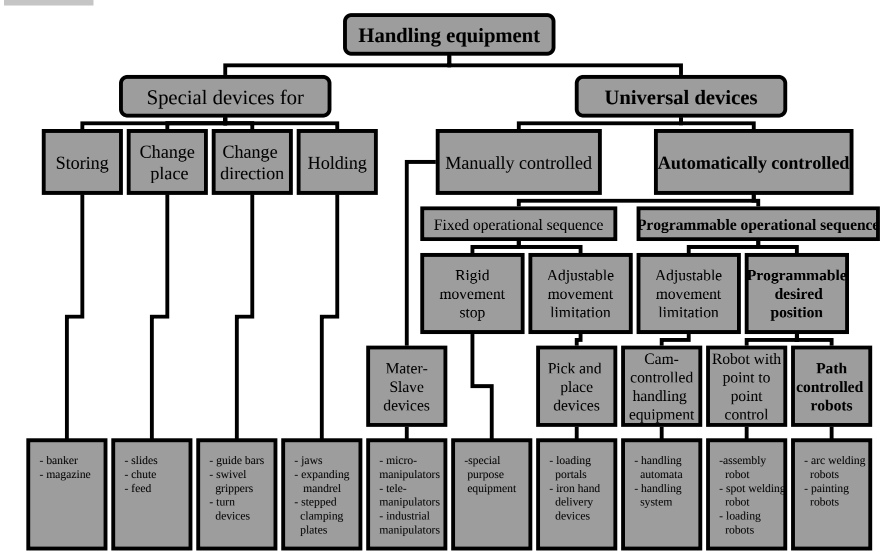
Definition of Industrial Robot (short version)



Industrial robot

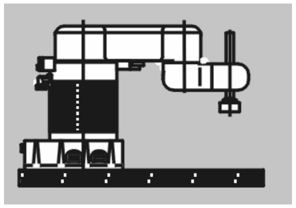


Part of car body with weld points



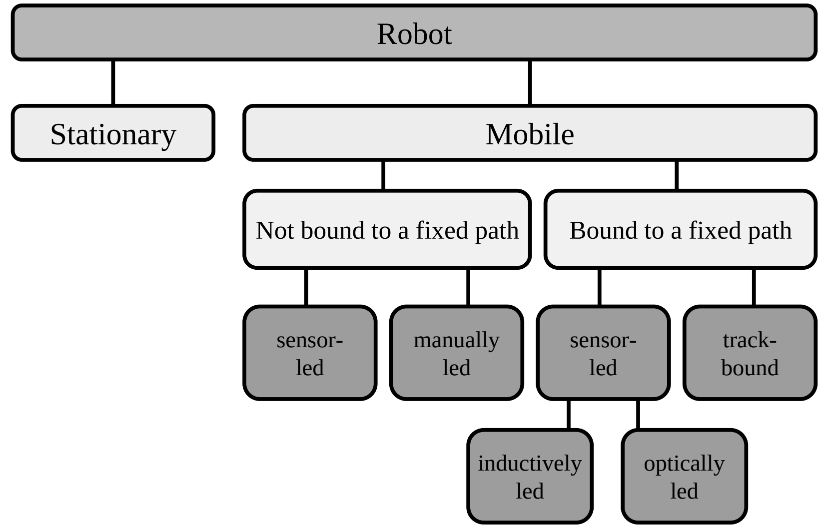
Systematic of the handling equipment

Industrial robots are **universally applicable** handling devices with **severa axes**, whose movements, regarding motion sequence and paths or angles, are **freely** (i.e. without mechanical intervention) **programmable** and if necessary are sensor-led.

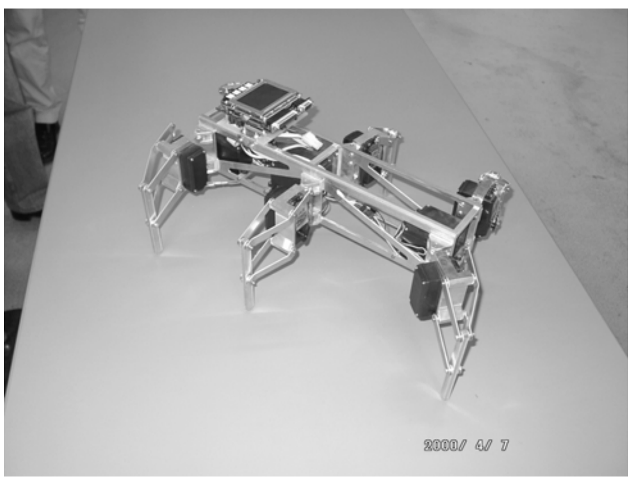


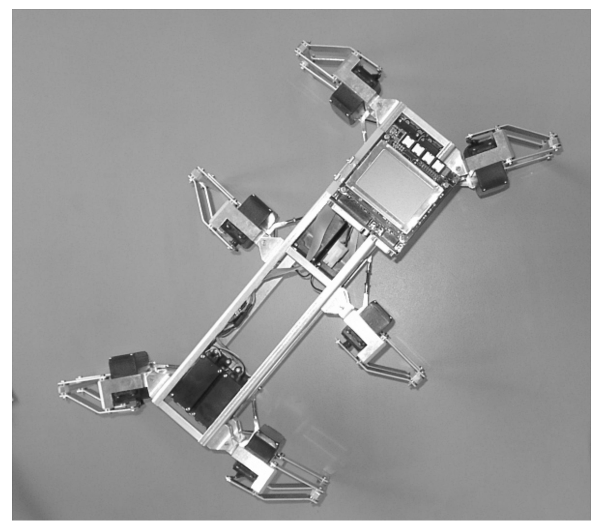
They are equipable with grippers, tools or other production devices and can execute handling and/or manufacturing functions

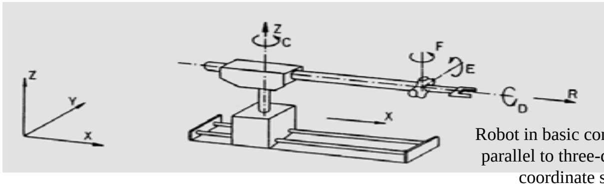
Definition of Industry Robot (complete version)



Structuring of the mobile Robots according to the type of the guidance



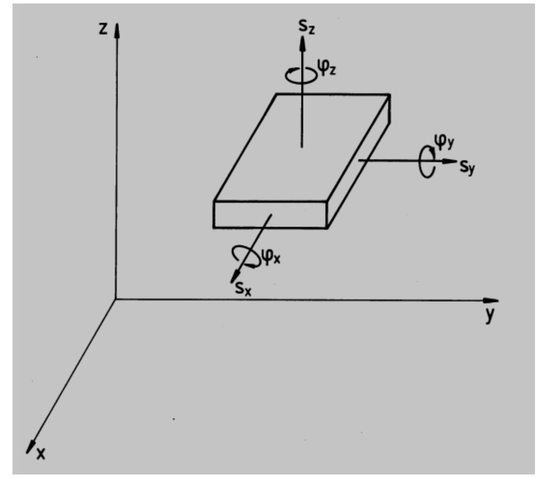




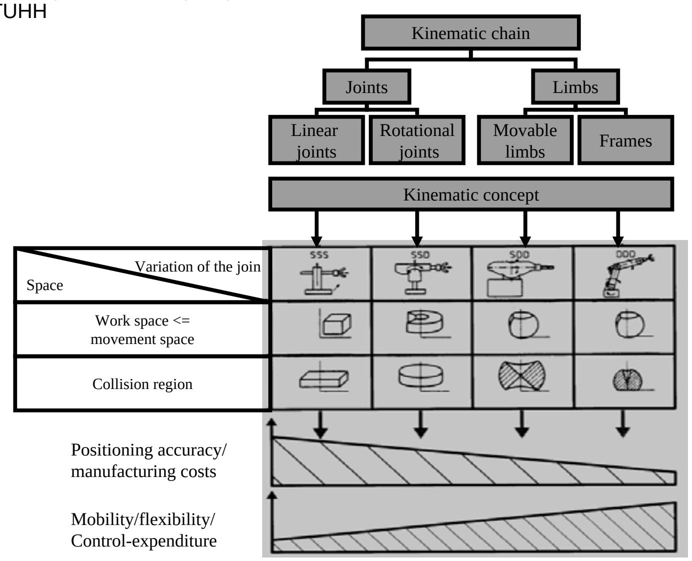
Robot in basic condition (axes parallel to three-dimensional coordinate system)

Axes denotation (according to VDI 2861)			
Axes denotation (according to VDI 2861)		Axes denotation (according to VDI 2861)	
X	horizontal main linear axis, parallel to the first axis of reference coordinate system	A	main axis of rotation parallel to the X-axis or other main axis of rotation*
Y	horizontal mail linear axis, parallel to the first axis of three-dimensional coordinate system	B	main axis of rotation parallel to the Y-axis or other main axis or rotation*
Z	vertical main linear axis, parallel to the third axis of reference coordinate system	C	main axis of rotation parallel to the Z-axis
		D	axis of rotation parallel to the X-axis or any axis of rotation, preferably 1st rotational secondary axis*
U	linear axis parallel to the X-axis or any linear axis		
V	linear axis parallel to the Y-axis or any linear axis	E	axis of rotation parallel to the Y-axis or any axis of rotation, preferably 2nd rotational secondary axis*
W	linear axis parallel to the Z-axis or any linear axis		
R	turnable linear axis (radial axis)	F	axis of rotation parallel to the Z-axis or any axis of rotation, preferably 3rd rotational secondary axis*
Q	second turnable linear axis (radial axis) or any axis		
		S	any axis
		T	any axis

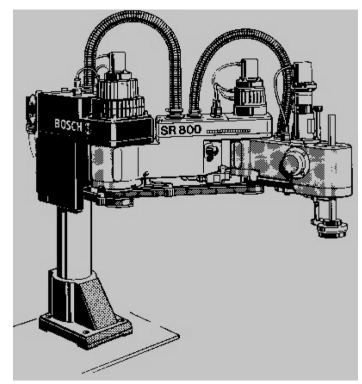
Denotation of IR Axes



Motion possibilities of a body in space

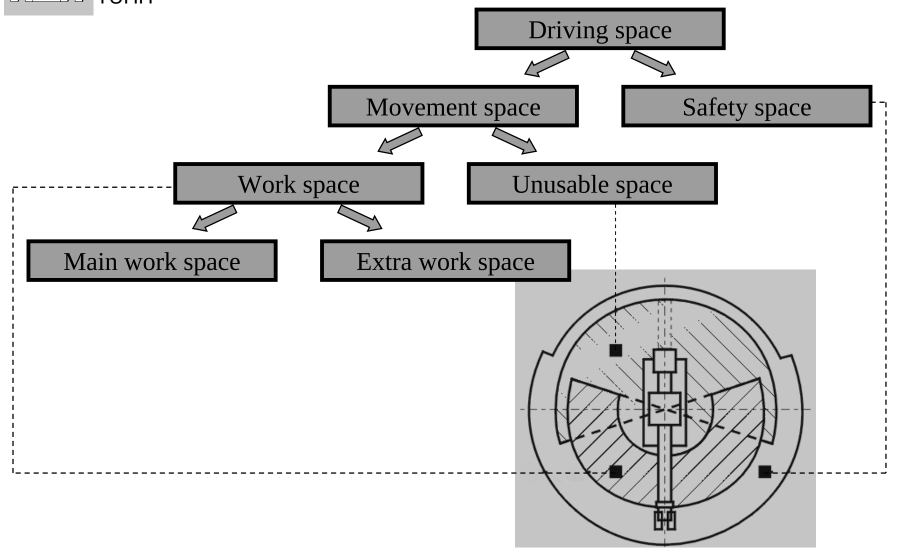


Kinematic conception of IR working space

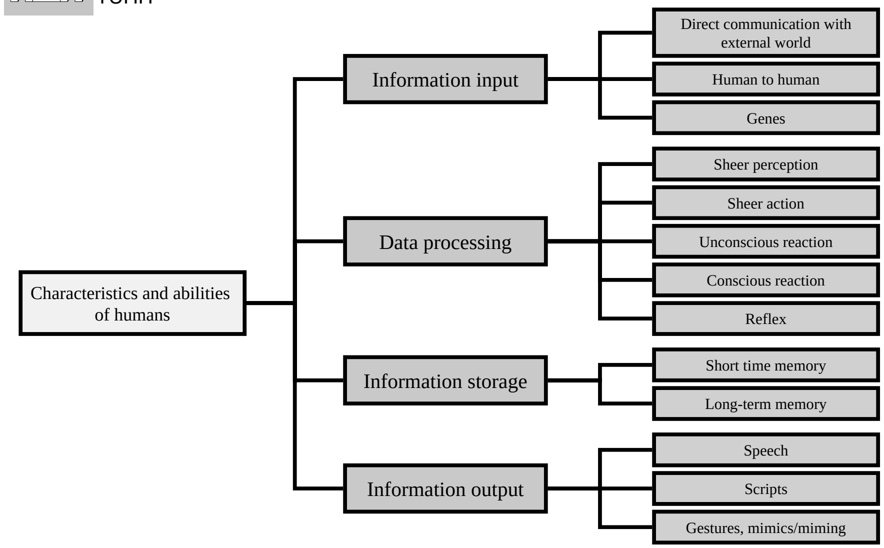


- Kinematics
- Drives
- Controls
- Sensors

Modules of a robot



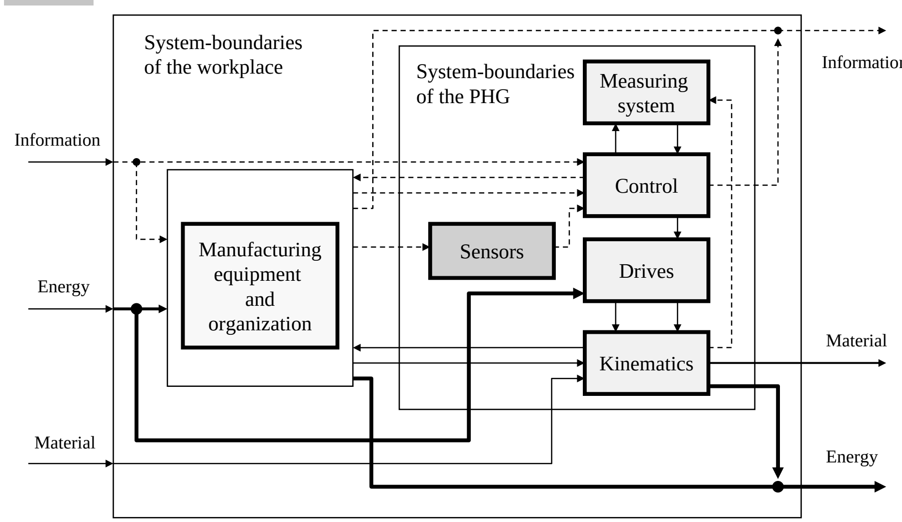
Space layout for robots after VDI2861



Characteristics and abilities of humans

Subsystems	Subfunctions
Kinematics	Generating the local allocation between workpiece/tool and manufacturing equipment
Functional elements	Access/supply workpiece
Control	Secure position of workpiece while moving
Drivers	To convert and supply the necessary energy to all movement axes
Measuring device	Measuring the position, speed and acceleration of single axis
Sensors	Acquisition of stochastic influences in the surrounding field of IR Measuring physical magnitudes Pattern and position recognition

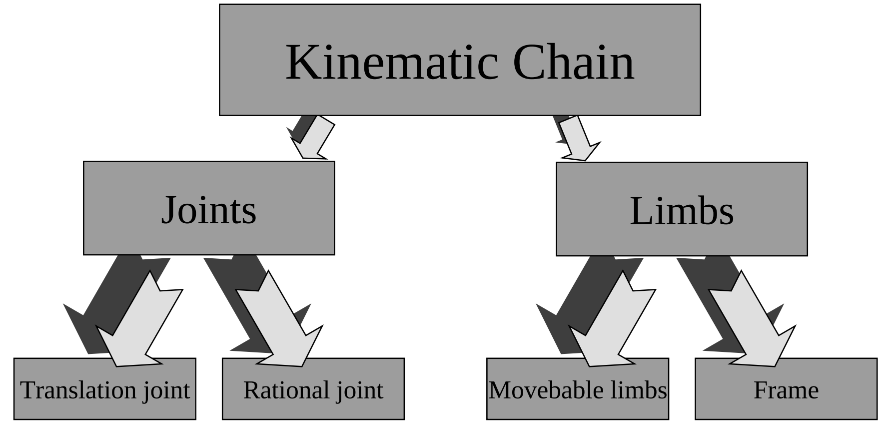
Subsystems of Robots



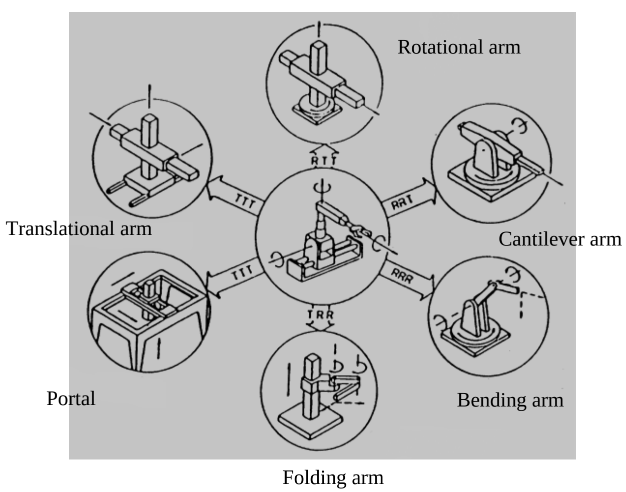
Structure of a workplace with robot

Subsystem	Task
Control	- Program execution, memory, controlling, monitoring - Logic combination, manufacture with equipment, peripheral device, - Other controls
Drives	- To convert and transfer the necessary energy to all movement axes
Kinematics	- Spatial correlation of workpiece/tool and manufacturing equipment - Start points, travel along of paths
Gripper	- To grasp and release objects - Secures the object during movement
Path- and speed acquisition	- Acquisition of stochastic influences from the surrounding field
Sensors	- Acquisition of stochastic influences from the surrounding field - Pattern and position recognition

Function of the subsystems

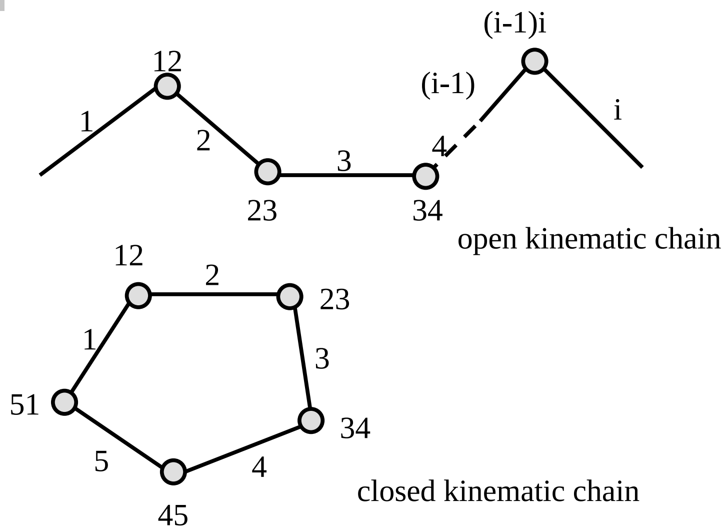


Parts of a kinematic chain

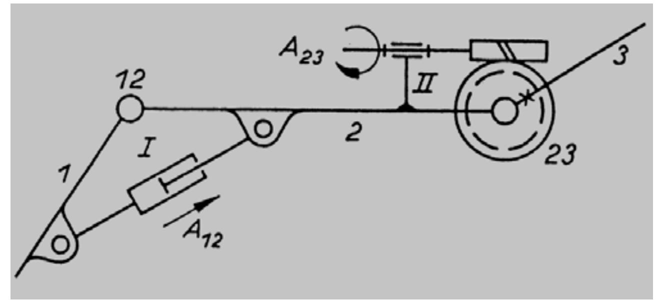


Kinematics of industrial robots

b	Possibility of movement	$b_{max} = 6$
u	Restrictions of movement for a joint	$u_{min} = 1$
f	Joint degree of freedom	$f = b - u$
F	Structural degree of freedom	$F = \sum f$



Kinematic chains

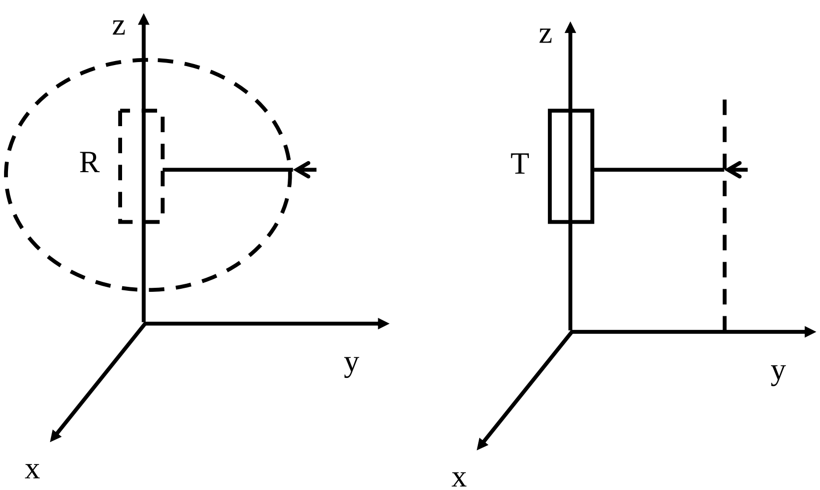


1, 2, 3 - parts of the open kinematic chain

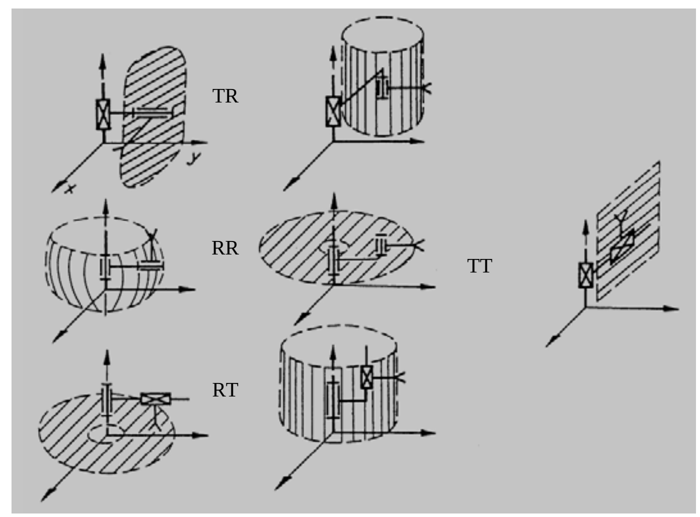
I, II - closed kinematic chain

A_{12}, A_{23} - actuators for joints 12 and 23

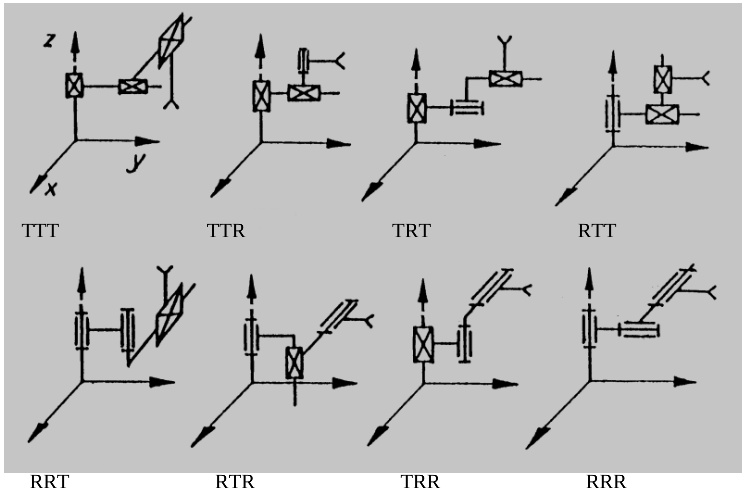
Multiple-drives system in serial arrangement



Structures with F=1



Structures for F=2



Structures for F=3

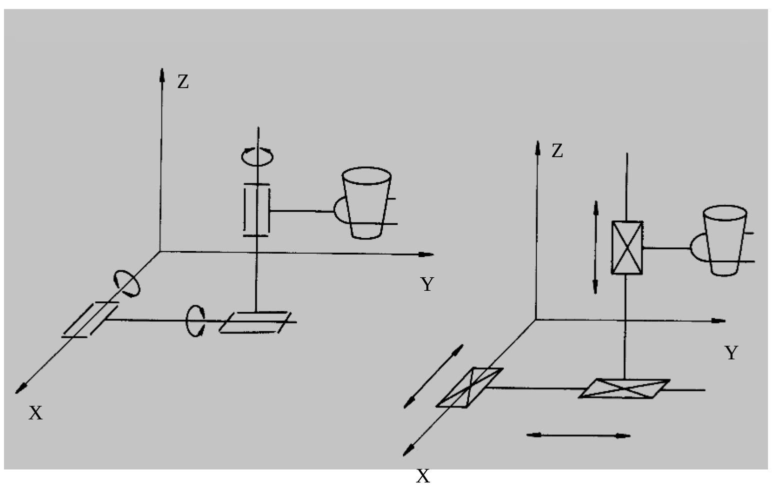
Axes structure / Joint structure	1	2	3	4	5
	│││	││ ─ ││ ●	│─│ │●│	│─ ─ │● ●	│─ ● │● ─
TTT	P	P	P	P	●
TTR	P	P	●	●	○
TRT	P	●	P	●	○
RTT	P	●	●	P	○
RRT	●	○	●	●	●
TTR	●	●	○	●	●
TRR	●	●	●	○	●
RRR	P	●	●	●	●

● Space-describing structure

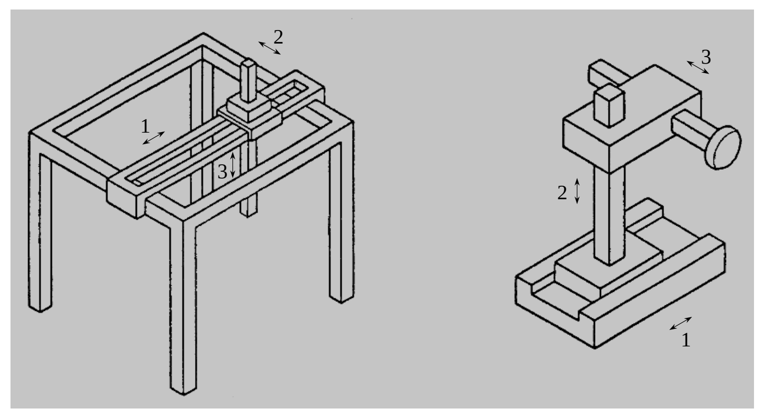
P structures with parallel translational axes, or three parallel axes of rotation

○ structures with a translational axes orthogonal relative to two parallel axes of rotation or with an axes of rotation orthogonal to two orthogonal translational axes

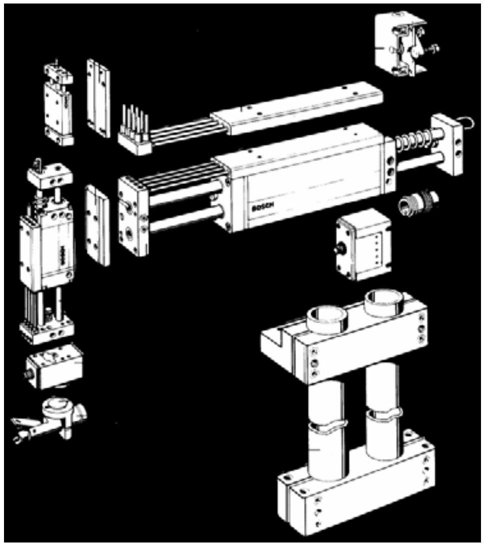
Structure variation for F=3



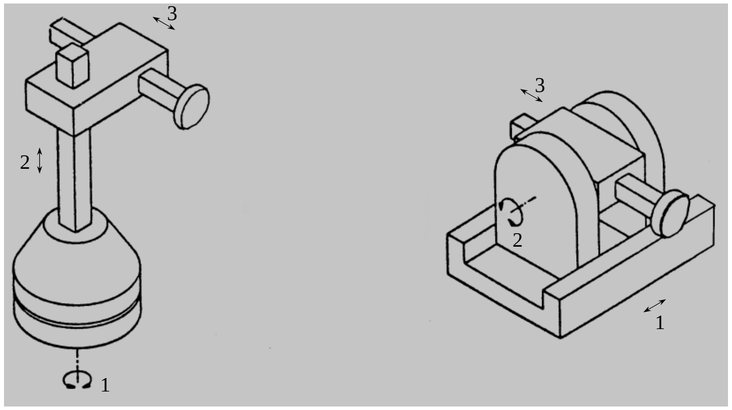
Positioning with RRR- and TTT-Structure



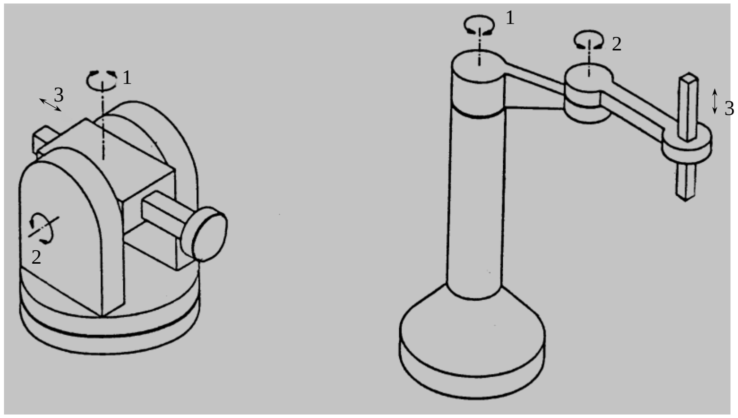
Industrial robot with TTT-Axes



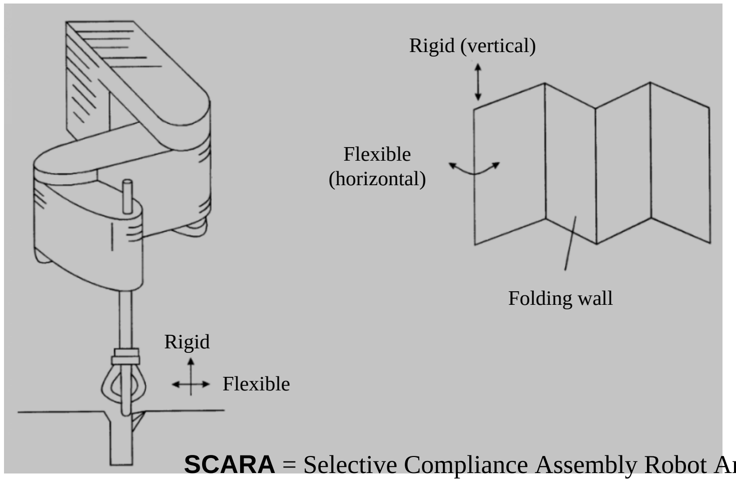
Linear axes for handling device



Industrial robot with TTR-Axes

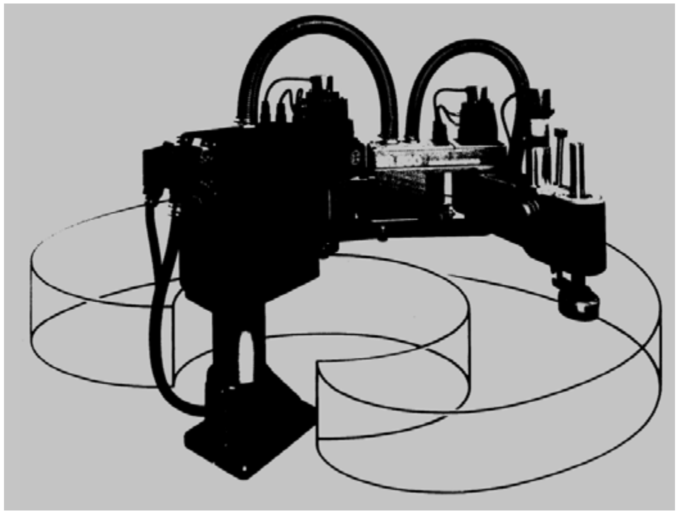


Industrial robot with TRR-Axes

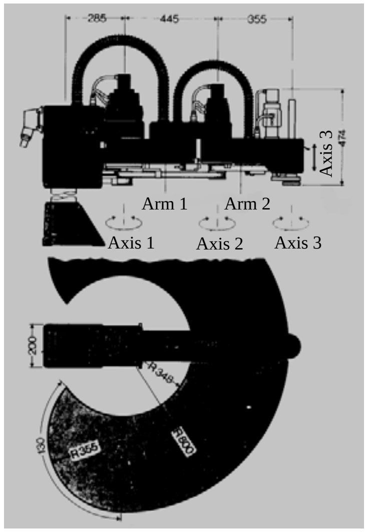


SCARA = Selective Compliance Assembly Robot Arm

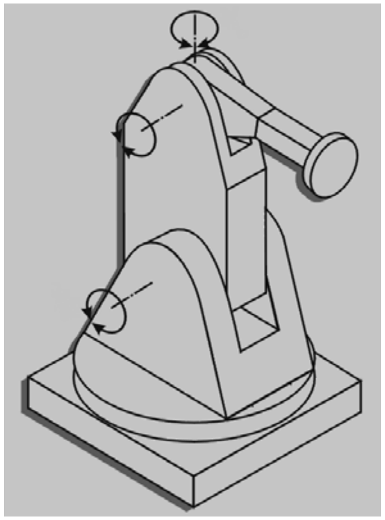
Definition SCARA



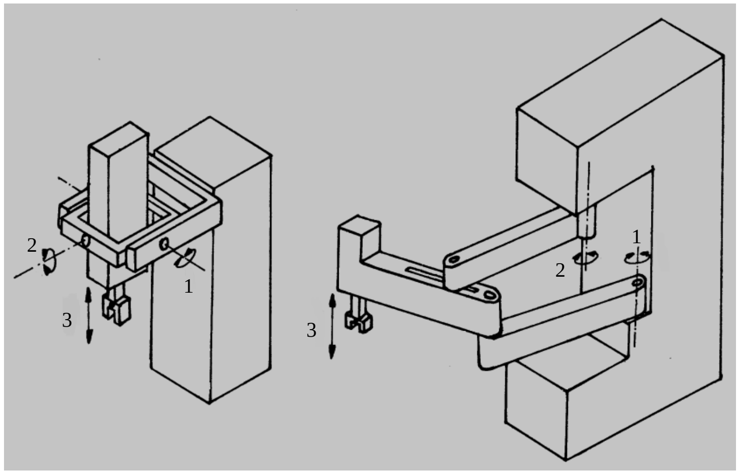
SCARA-Robots



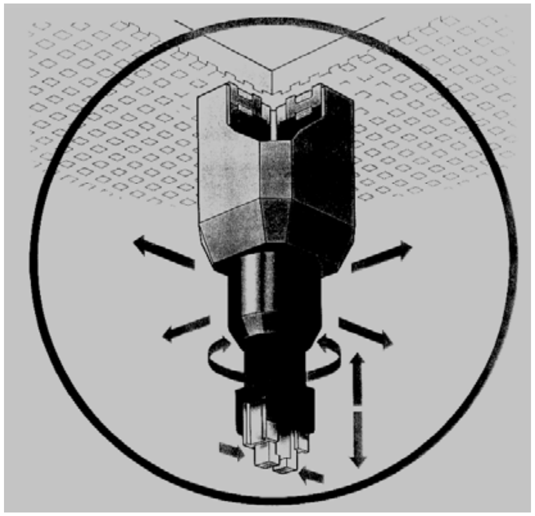
Swivel (rotating) arm robot SR 800



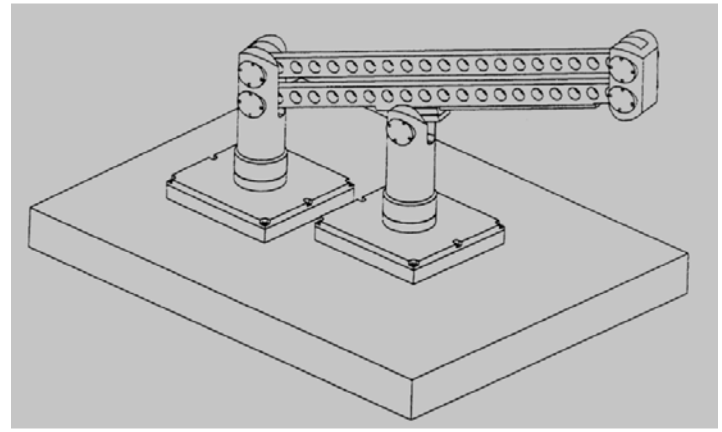
Industrial robot with RRR-Axes



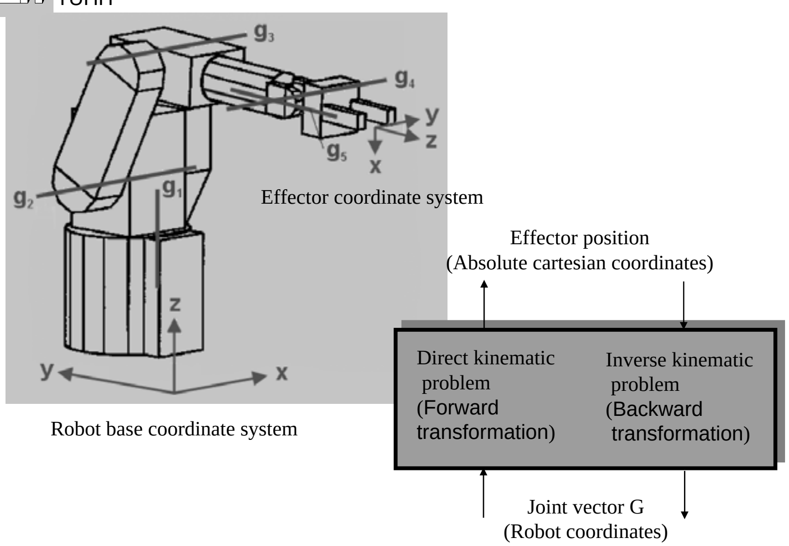
Special designs of industry robots



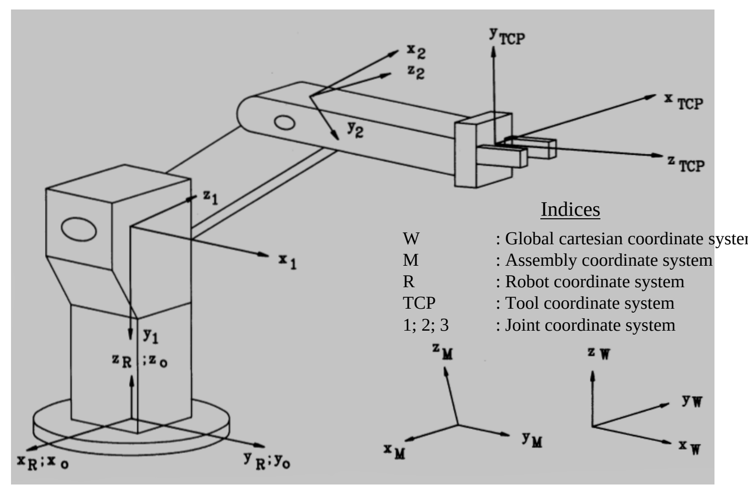
2D-displaceable robot



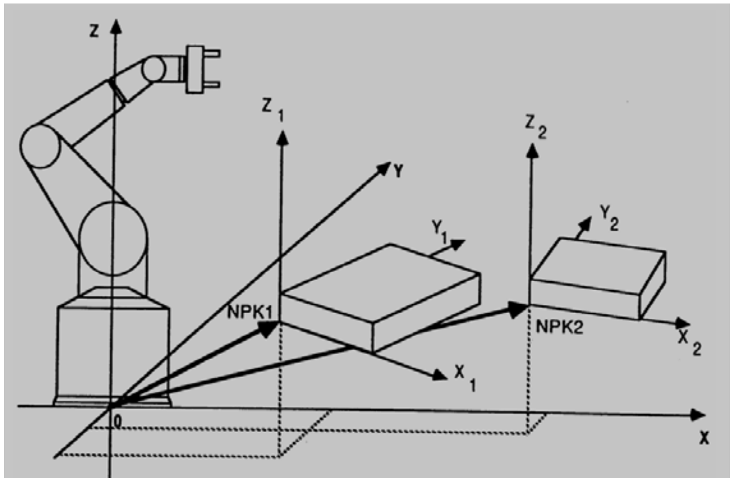
Modular handling and positioning system with direct drives



Kinematic relation for robot arm



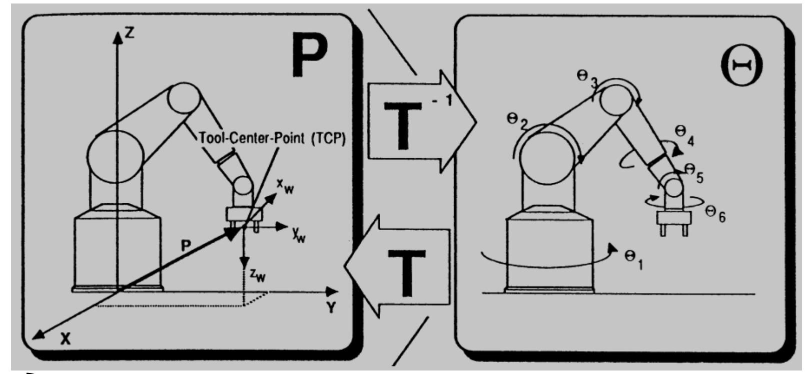
Coordinate system of an IR



NPK: reference point offset correction

Industrial robot with RRR-Axes

Backward-transformation



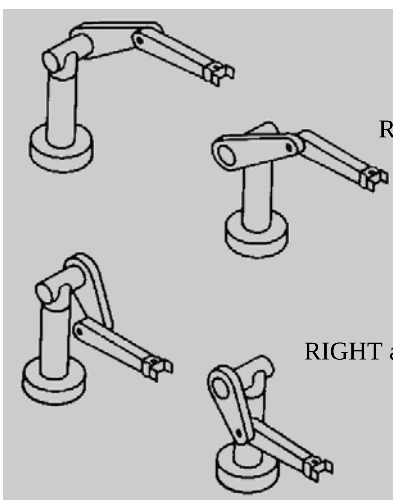
Forward-transformation

X_w, Y_w, Z_w } Tool coordiante system

Θ_n : Angle between axes

Transformation of cartesian position data in axis information

LEFT and ABOVE



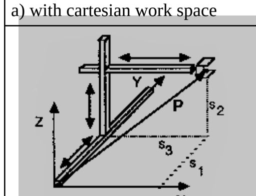
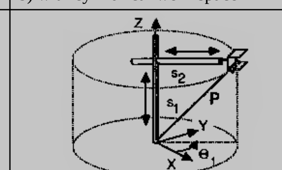
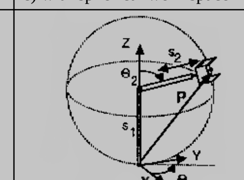
RIGHT and ABOVE

LEFT and DOWN

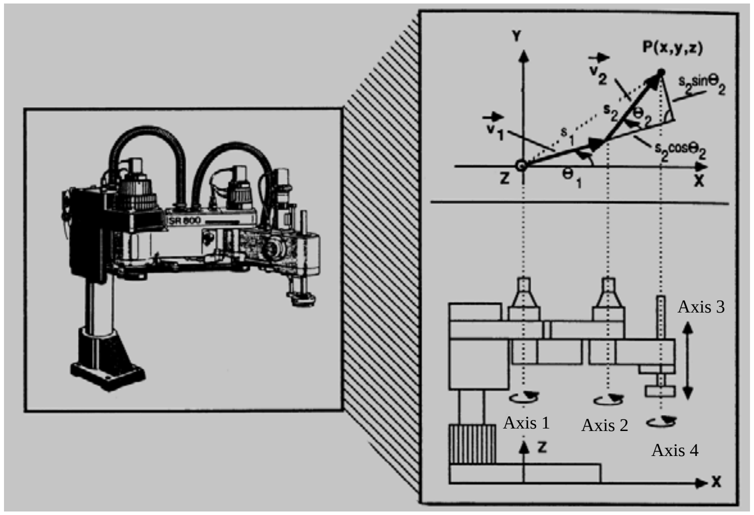
RIGHT and DOWN

Arm configuration at joint robots

3-axis industrial robots

a) with cartesian work space	b) with cylindrical work space	c) with spherical work space
		
• 3 linear joints	• 1 rotational joint • 3 linear points	• 2 rotational joint • 3 linear points
• Position of the effector $\vec{P} = \begin{vmatrix} x \\ y \\ z \end{vmatrix} = \begin{vmatrix} s_3 \\ s_1 \\ s_2 \end{vmatrix}$	• Position of the effector $\vec{P} = \begin{vmatrix} x \\ y \\ z \end{vmatrix} = \begin{vmatrix} s_2 \cos\theta_1 \\ s_2 \sin\theta_1 \\ s_1 \end{vmatrix}$	• Position of the effector $\vec{P} = \begin{vmatrix} x \\ y \\ z \end{vmatrix} = \begin{vmatrix} s_2 \sin\theta_2 \cos\theta_1 \\ s_2 \sin\theta_2 \sin\theta_1 \\ s_2 \cos\theta_2 + s_1 \end{vmatrix}$
• Axis positions $s_1 = y$ $s_2 = z$ $s_3 = x$	• Axis positions $\theta_1 = \arctan\frac{y}{x}$ $s_1 = z$ $s_2 = \sqrt{x^2 + y^2}$	• Axis positions $\theta_1 = \arctan\frac{y}{x}$ $\theta_1 = \arccos\frac{z - s_1}{s_2}$ $s_2 = \sqrt{x^2 + y^2}$

Determination of the axis positions for 3-axis industrial robots



Kinematics of a rotational joint robot

$$n_1 = s_1 \begin{vmatrix} \cos u_1 \\ \sin u_1 \end{vmatrix}$$

$$n_1 = s_2 \begin{vmatrix} \cos(u_1 + u_2) \\ \sin(u_1 + u_2) \end{vmatrix}$$

$$p = \begin{vmatrix} x \\ y \end{vmatrix} = \begin{vmatrix} s_1 \cos u_1 + s_2 \cos(u_1 + u_2) \\ s_1 \sin u_1 + s_2 \sin(u_1 + u_2) \end{vmatrix}$$

With the application of the cosine law the position angles of axis 1 and 2 follow

$$u_1 = \arctan \frac{y}{x} - \arctan \frac{s_2 \sin u_2}{s_1 + s_2 \cos u_2}$$

with

$$\cos\gamma = \cos(180 - u_2) = -\cos u_2$$

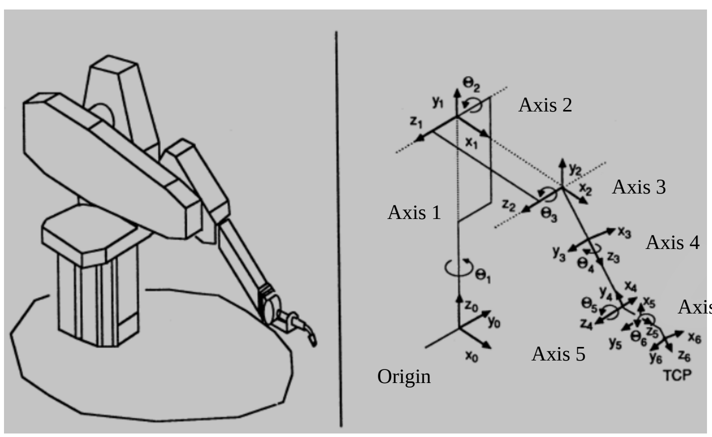
$$u_2 = \arccos \frac{x^2 + y^2 - s_1^2 - s_2^2}{2 s_1 s_2}$$

and

$$u_1 = \arctan \frac{y}{x} - \arctan \frac{s_2 \sin u_2}{s_1 + s_2 \cos u_2}$$

with s1, s2 as characteristic data of the kinematic chain

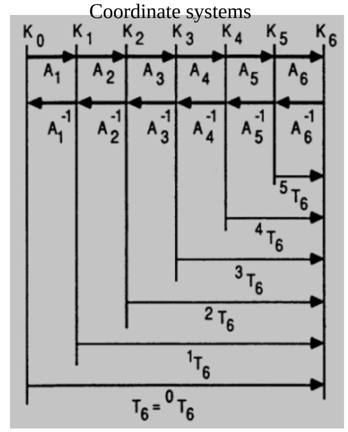
Positioning for axis 1 and 2



Kinematics of a 6-axis folding arm robot

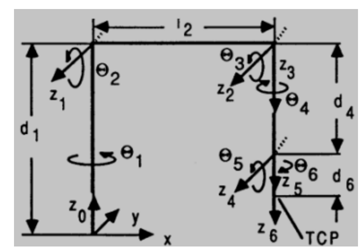
a) Graph of the transformations for 6-axis robots

Coordinate systems



Matrix of transformation:
$T_6 = A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5 \cdot A_6$

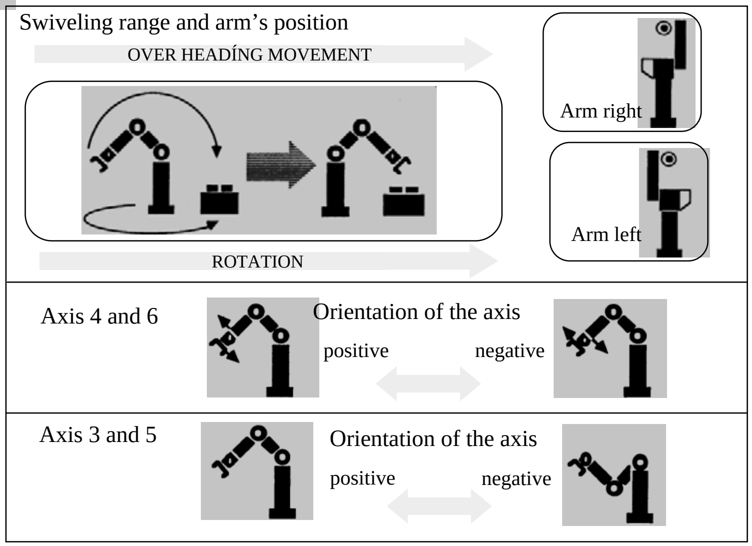
b) Position of the joint coordianate system



c) Joint parameters according to Hartenberg-Denavit

Joint	Variable	θ	l	d	α
1	θ_1	θ_1	0	d_1	π/2
2	θ_2	θ_2	l_2	0	0
3	θ_3	θ_3	0	0	π/2
4	θ_4	θ_4	0	d_4	-π/2
5	θ_5	θ_5	0	0	π/2
6	θ_6	θ_6	0	d_6	0

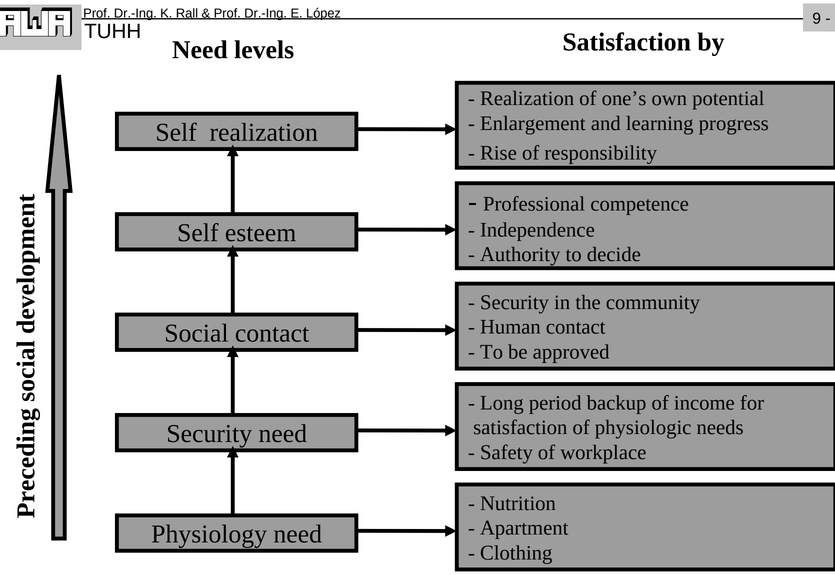
Backward transformation for a 6-axis folding arm robot



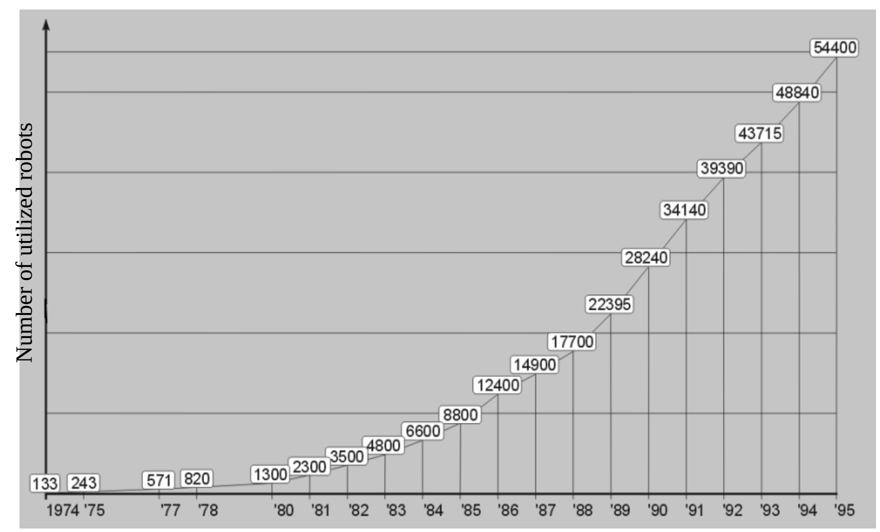
Ambiguites of the transformation at 6-axes folding arm robot

Ende Abschn. 1

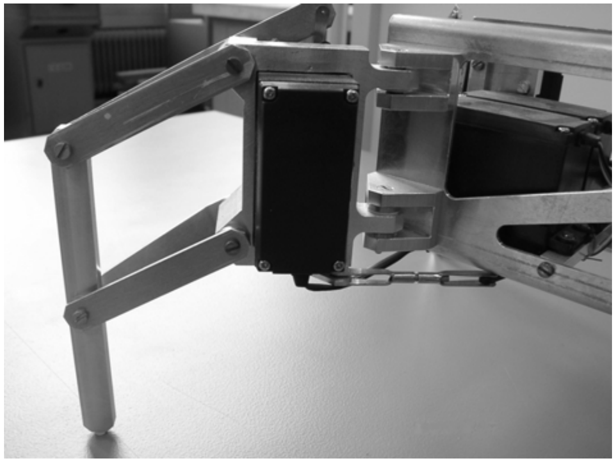
- Es folgen Reservebilder.

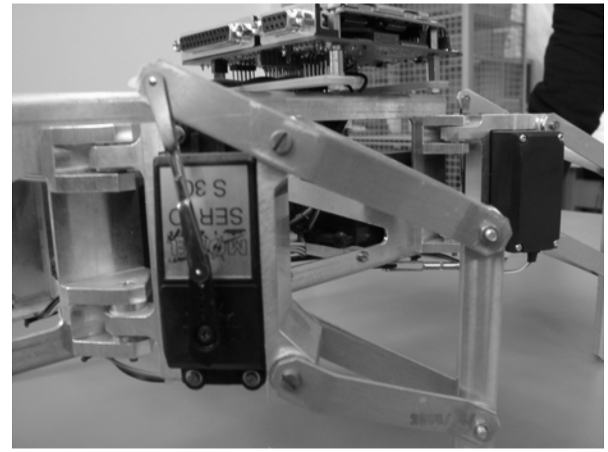


Hierarchy of need



Development of industrial robots in Germany





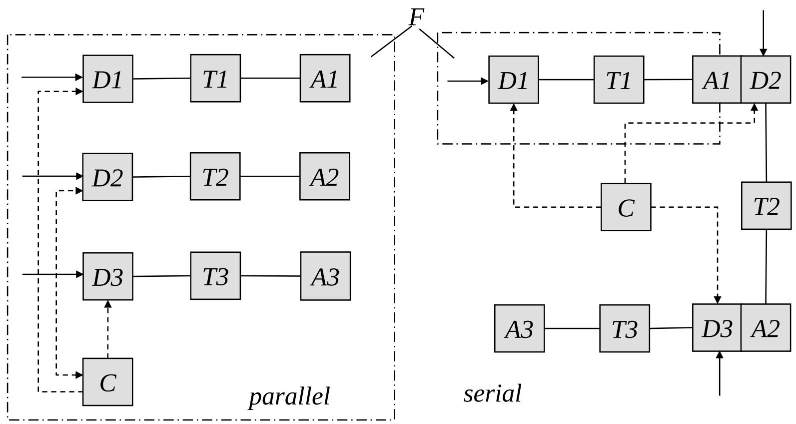
Beginn Abschnitt 2

Necessary → exact description: geometrical
cinematical
dynamical demands
on the robots structure

path (distance, form, given points)
time (cycle time, acceleration, speed)
force (weight, inertia, function)

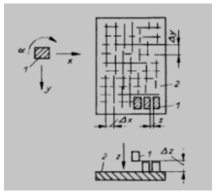
- path- time and force- specification have an important influence on robots structure
- flexibility is an additional important demand on robots

Demands on Robots structure

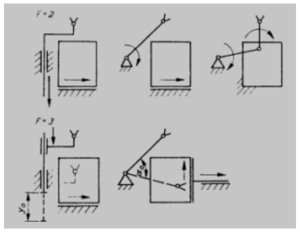


D - Drive element, T - Transmission element, A - Actuator, C - Control element, F - frame

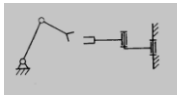
Basic structure of Multi-drives system



Palletization of workpieces

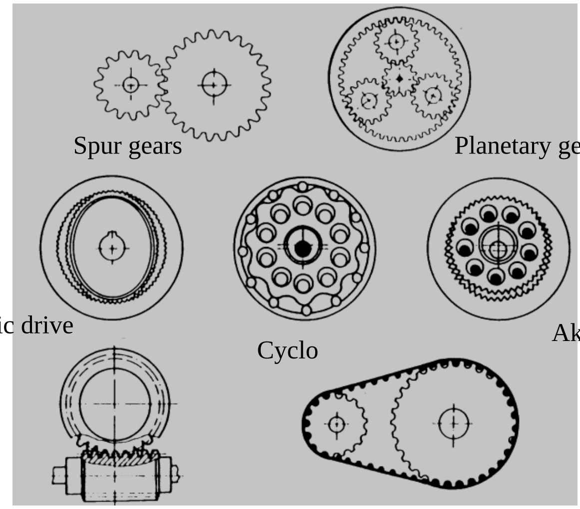


Differnt structures for solving palletizing tasks

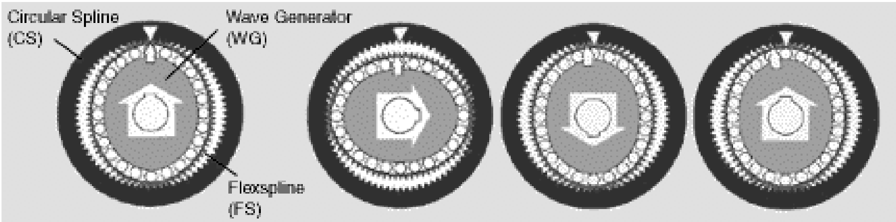


Simplified co-operatin structure

Influence of handling tasks on IR-structure



Transmission for robot axes of rotation



An elliptical body (wave generator) deforms a flexible, interlocked body over the balls and the bearing cup (flexible spline)

The turn of the wave generator causes a displacement of the meshing region

... results in a full rotation of the wave generator a torsion of the flexible splines in accordance with the number of teeth different...

Since the number of teeth at the circular spline and flexible spline is different...

Method of operation of the Harmonic drive

Electrical equipment with industrial robots

Advantages

- extremely precise
- it can be arranged easily in such a way that no movements would easily occur in the case of energy disturbance
- automatic control loops
- small noise
- inexpensive through standardized components
- strength of three-phase drives

Disadvantages

- bad strength and/or power density
- frequently cooling equipment often necessary
- adjustable three-phase current drives are complex
- unfavorable dynamic behavior
- almost always mechanical transmission necessary

Electrical equipment with industrial robots

Pneumatic equipment with industrial robots

Advantages

- cheap
- easy to install
- pneumatic contacts are usually available
- precise positioning by stops is possible
- simple control
- very reliable
- small maintenance costs
- not influencable through electrical fields

Disadvantages

- limited stokes
- reprogramming of the firm installed control units is expensive
- only limited number of programs are practical
- uncontrolled movement is possible
- control chain
- noise
- air supply is partially problematic (cleanness, constant pressure level)

Pneumatic equipment with industrial robots

Hydraulics at Industrial robots

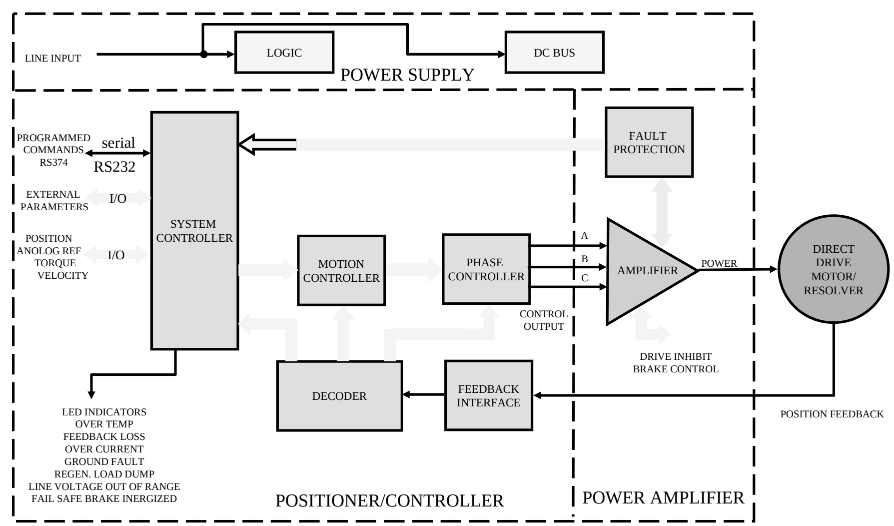
Advantages

- very good strength and/or power density
- good dynamic behavior
- closed-loop control systems are practicable
- very reliable
- standardized elements are available

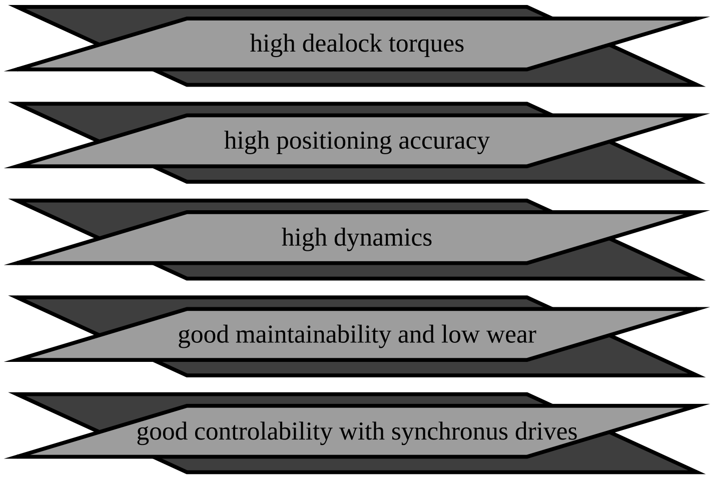
Disadvantages

- hazard with circuit break (in particular in the case of high pressure hydraulics)
- oil must be well filtered
- leakage
- temperature dependence
- combustibility of the hydraulic fluid
- within some areas not applicable (food industry, hospitals, clean room)
- without mechanical additional equipment there is no automatic locking

Hydraulics at Industrial robots



Block diagram of a drive regulation for a direct drive (Slo-Syn)

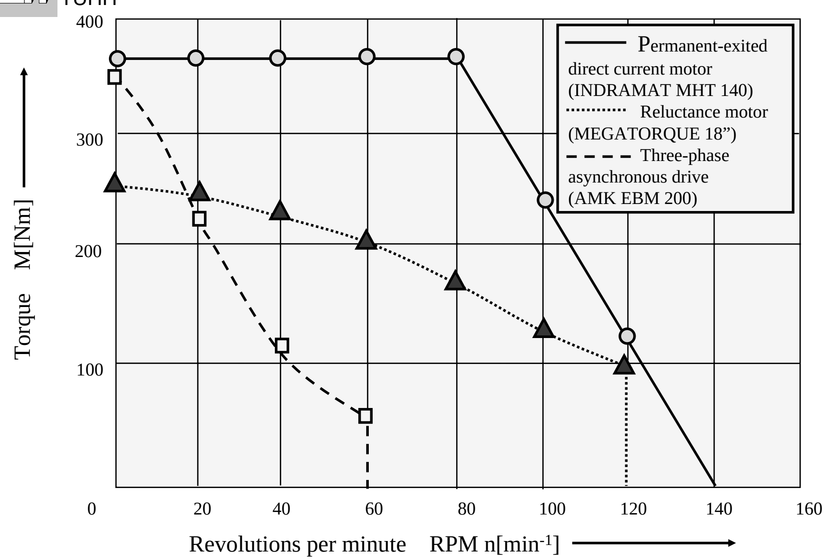


Features of Direct drives in Industrial robots

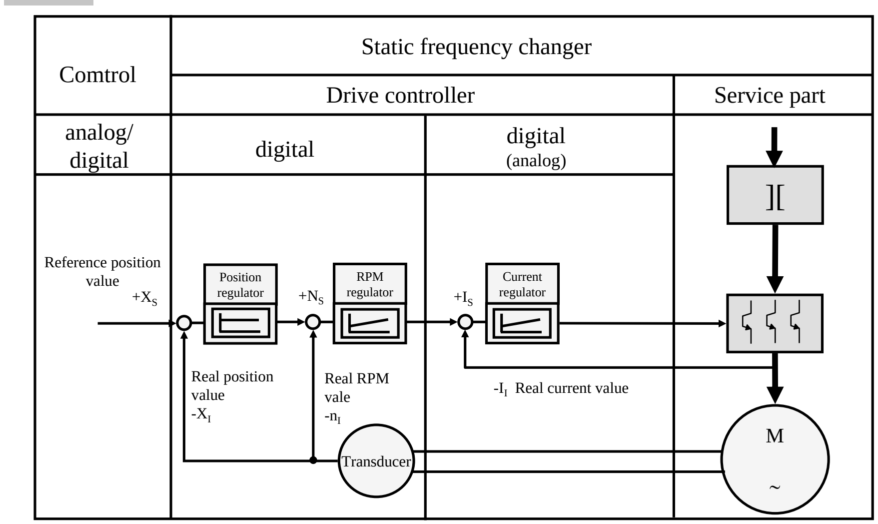
	Synchronous drives	Asynchronous drives	Reluctance motors
Dynamics	●	●	◆
Overload range	●	●	◆
Positioning	●	●	○
Rotary speed region	●	●	●
Degree of efficiency	●	◆	◆
Torque weight	◆	○	●
Standard outlay	●	○	◆
Temperature behavior	●	○	◆
Drive costs	○	●	●
Converter costs	◆	○	◆

● = good ◆ = middle ○ = bad

Evaluation of different drive concepts for direct drives



Characteristics of different direct drives

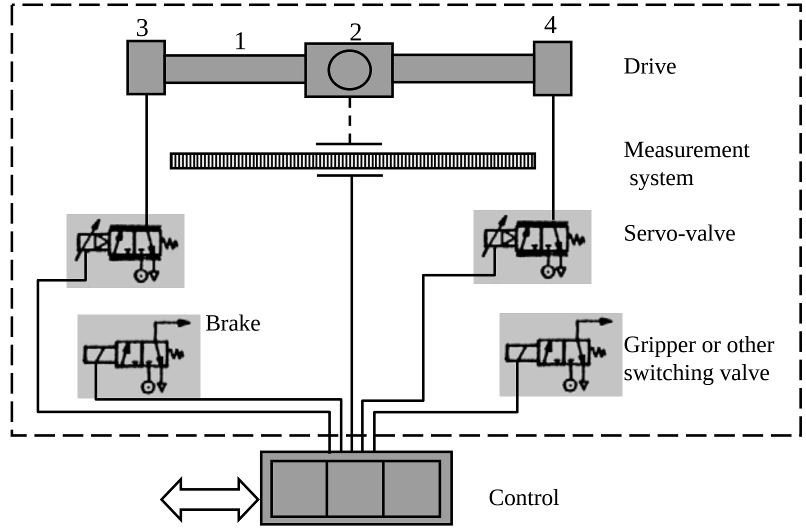


Design of a digital drive control

Ende Abschnitt 2

- Es folgen Reservebilder.

NC (Numerical Modul) - Drive modul



Components of pneumatic Servo-Drive Systems

Beginn Abschnitt 3 Greifer

Main functions of a gripper

Execute a position-securing force on a workpiece

⇩ **Gripp**
⇩ **Hold**
⇩ **Release**

Auxiliary functions

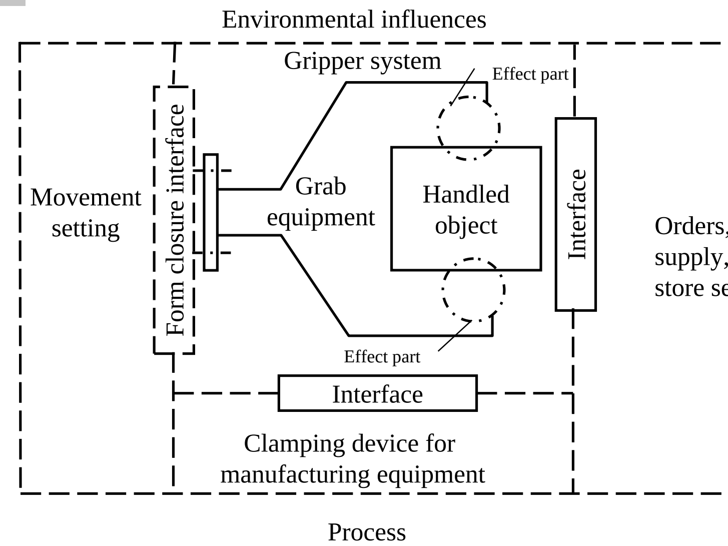
⇩ Centering
⇩ Orienting
⇩ Executing additional movements
⇩ Collecting information about workpieces

Main functions of a gripper

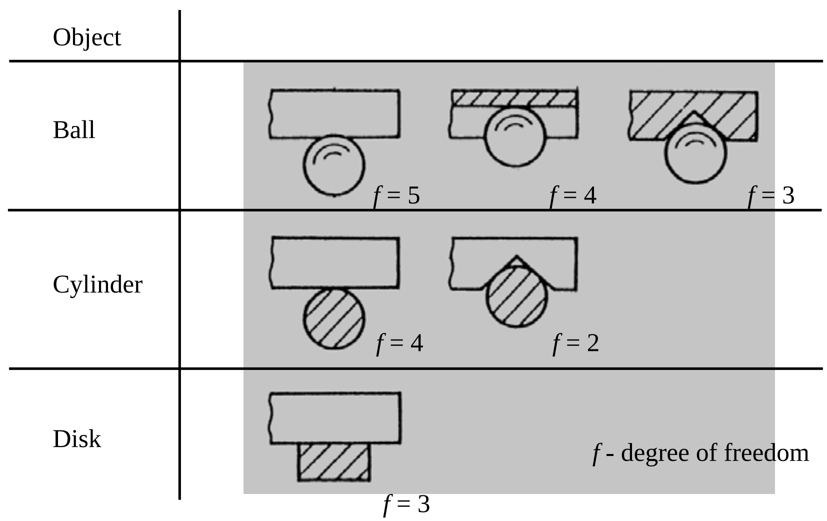
Factors of influence on gripper construction

Handling object	Handling equipment	Peripheral device	Handling function	Environment
Amount Mass Material Temperature Handle areas Dimensions Sensitivity Forms Moment of inertia Tolerance	Mounting-position Storing position Positioning-accuracy Process forces Accessibility Preparation time Inset-Withdrawal-forces	Position-accuracy Acceleration Type of energy Connection-dimension Control Pay load	Functions Lot size Cycle time	Contamination Moisture Vibrations Temperature

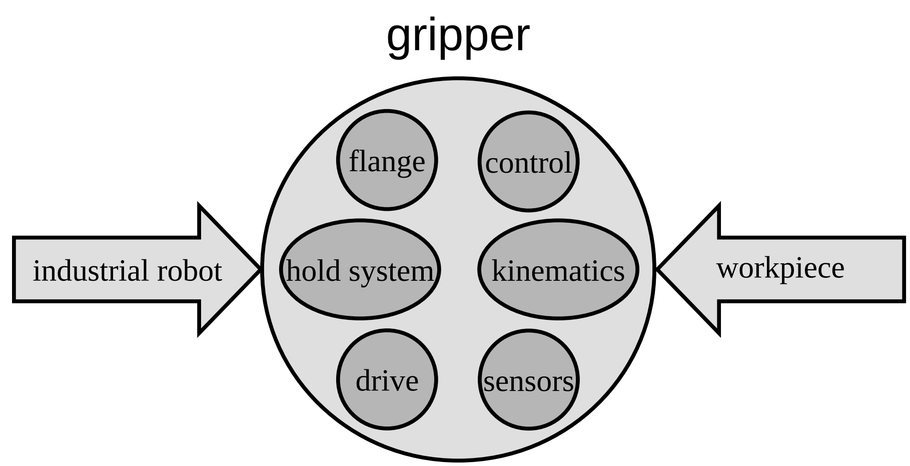
Factors of influence on the gripper construction



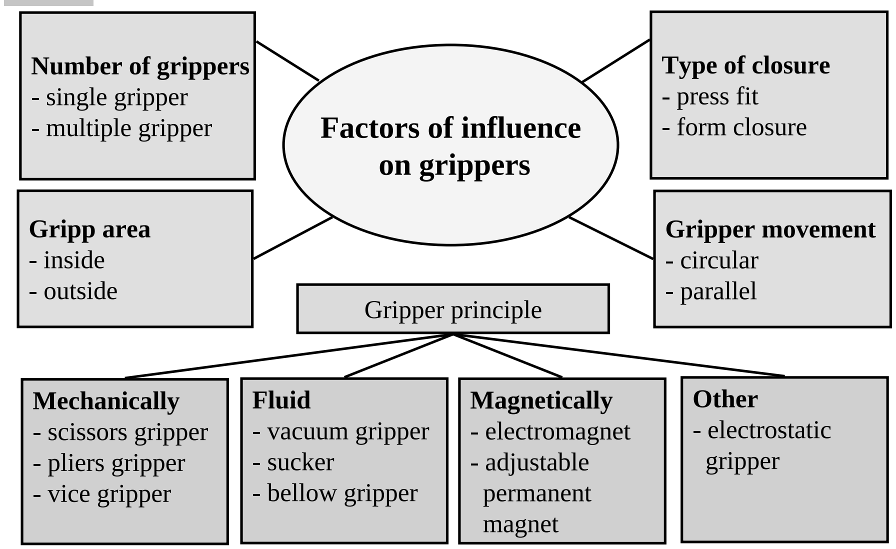
Interfaces of a gripper arangement



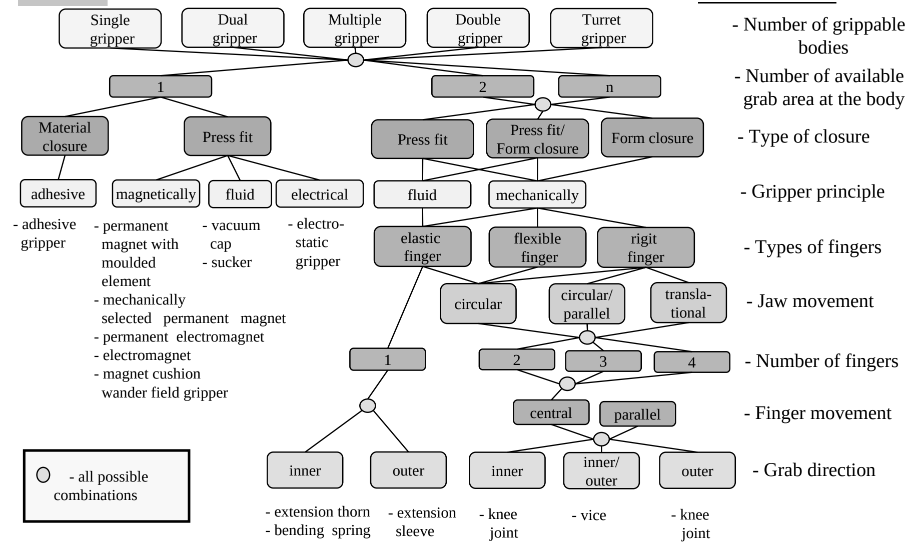
Degrees of freedom between object and gripper



Gripper with its Subsystems



Factors of influence on grippers



Systematics of the grippers

number of workpieces \ operation	to only activate together	to activate separately
1 workpieces	single gripper	
2 workpieces	dual gripper	double gripper
n workpieces	multiple gripper	turret gripper

Kinds of the grippers

Hold principles of grippers

Hold by press

Hold by Friction forces
- Direct clamping e.g. with compressed air subjected diaphragm
- Indirect clamping by active pressing of mobile items (gripper finger)
- Indirect clamping by under effect of gravity force self-locking mechanisms

Hold by Negative pressure forces
- Adhesion suction apparatus
- Vacuum suction apparatuses admitted by a vacuum pump
- Venturi nozzle and vacuum suction apparatus (vacuum generation through overpressure)

Hold by Magnetic forces
- Permanent magnets
- Permanent magnets with electrical field displacement
- Electromagnets

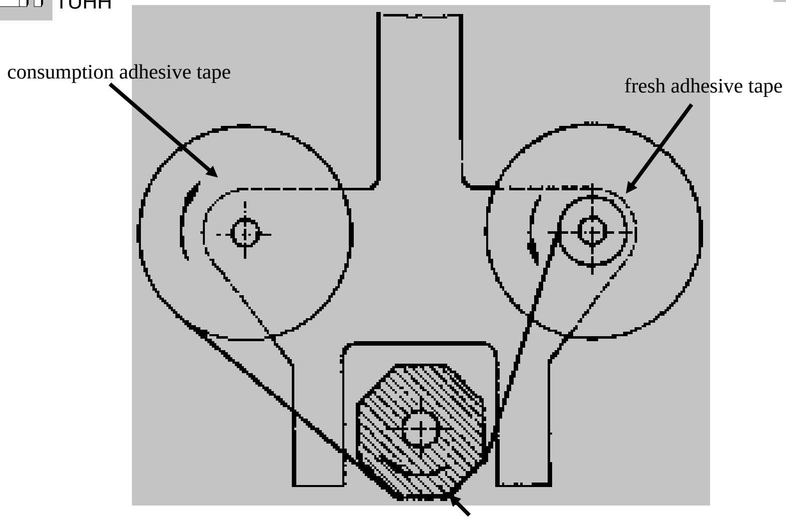
Hold by Intermolecular forces
- Adhesion foils

Hold by form closure

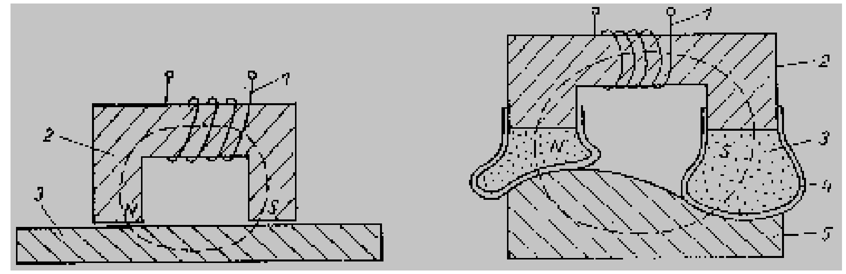
Hold by pairs of form items
- Rigid form elements on the gripper form negative copy from shape of the wokpiece elements
- Flexible modeling jaws are modeled at part form elements

Hold by throatiness hooking
- Pricing of needles into the handling object (e.g. textiles, foam material, etc.)

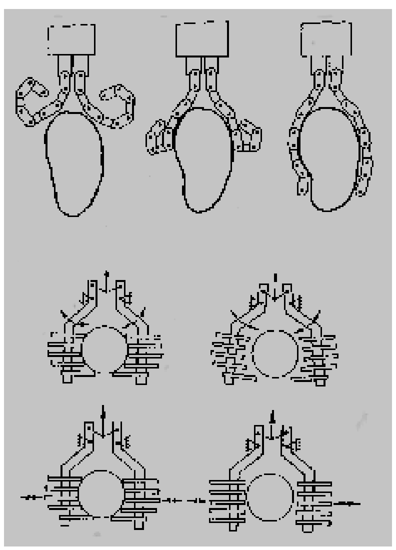
Hold principles of grippers



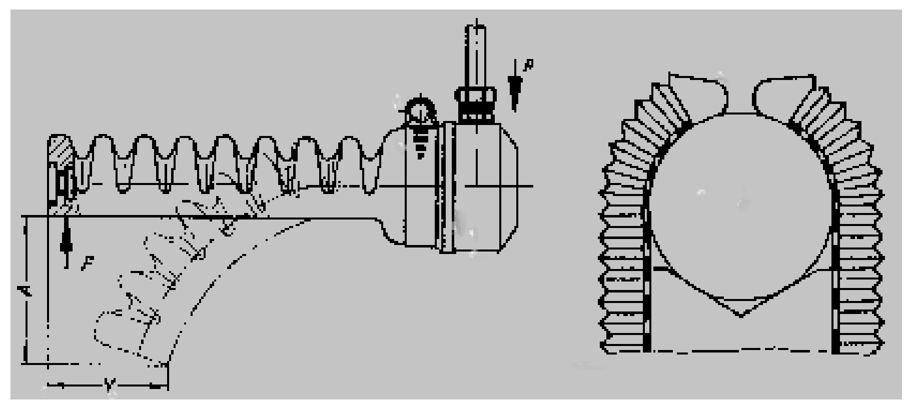
Gripper with adhesive tape



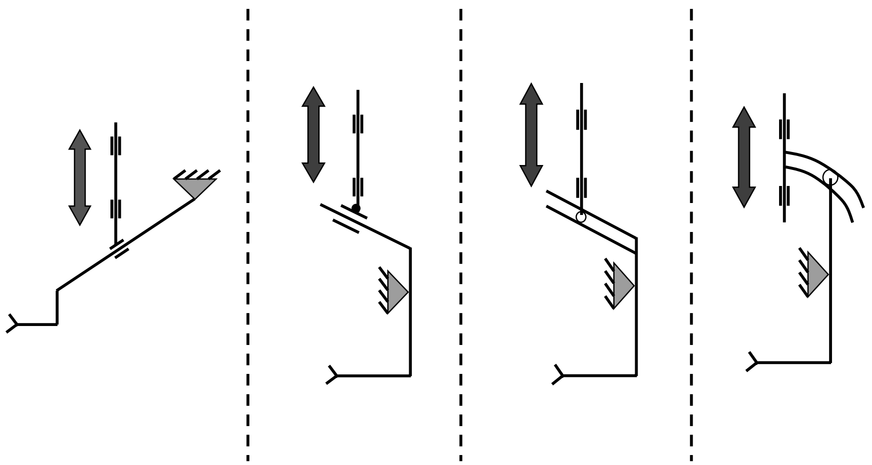
Gripper with electromagnet



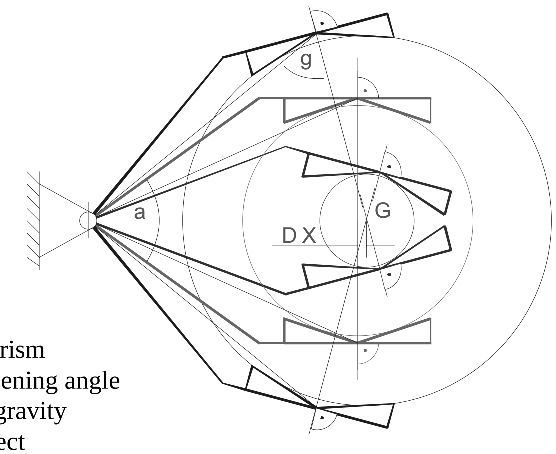
Mechanical enclosure gripper



Pneumatic bending finger

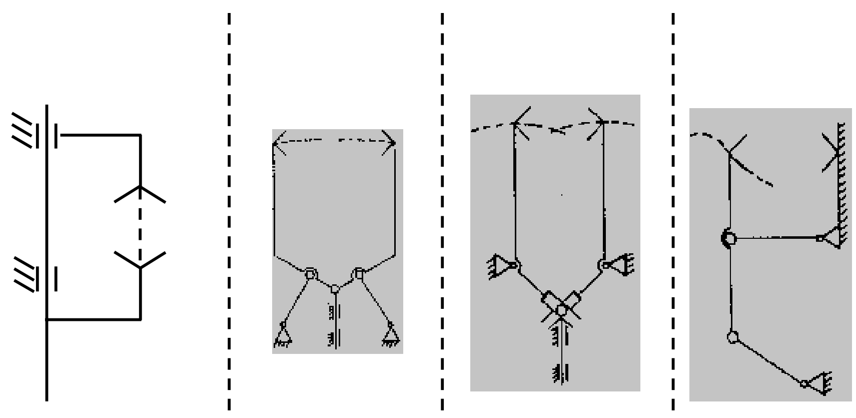


Rotational movement with linear drive



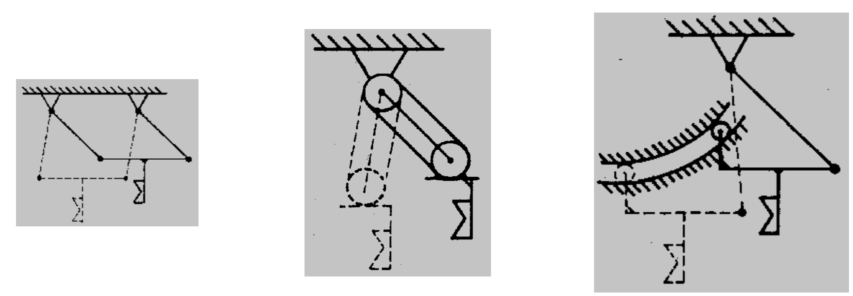
γ = Angle of prism
α = Gripper opening angle
G = Center of gravity of the object
ΔX = Displacement

Center displacement with scissors grippers



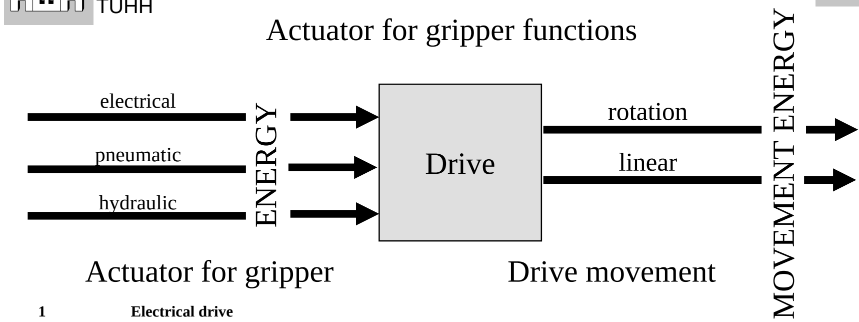
1 2 3 4

Kinematics for grippers



Parallel guidance of gripper jaws

Actuator for gripper functions



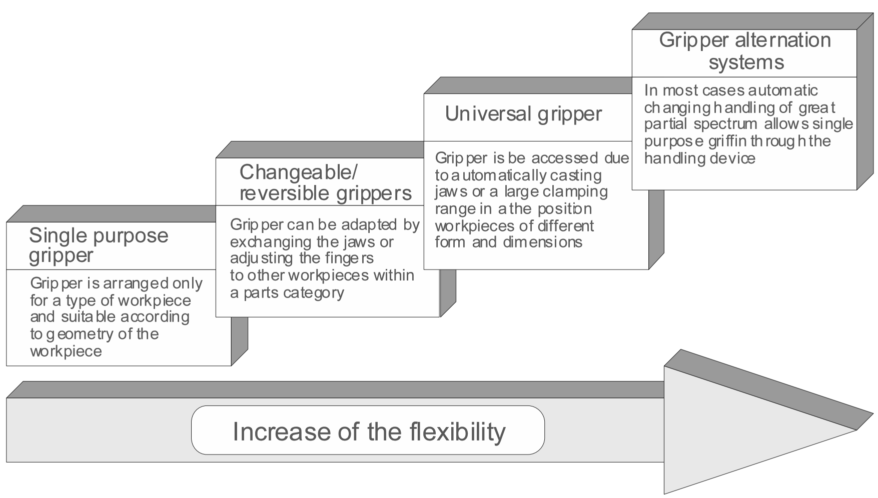
1	**Electrical drive**	
1.1	Stepping motor	rotation
1.2	Direct current motor	rotation
2	**Pneumatic drive**	
2.1	Pneumatic cylinder	linear
2.2	Pneumatic motor	rotation
2.3	Swivel cylinders (low number of revolutions per minute, limited rotation angle)	rotation
3	**Hydraulic drive**	
3.1	Hydraulic cylinder	linear
3.2	Hydraulic motor (unlimited rotation angle)	rotation
3.3	Swivel cylinders (limited rotation angle)	rotation

Actuators for gripper functions

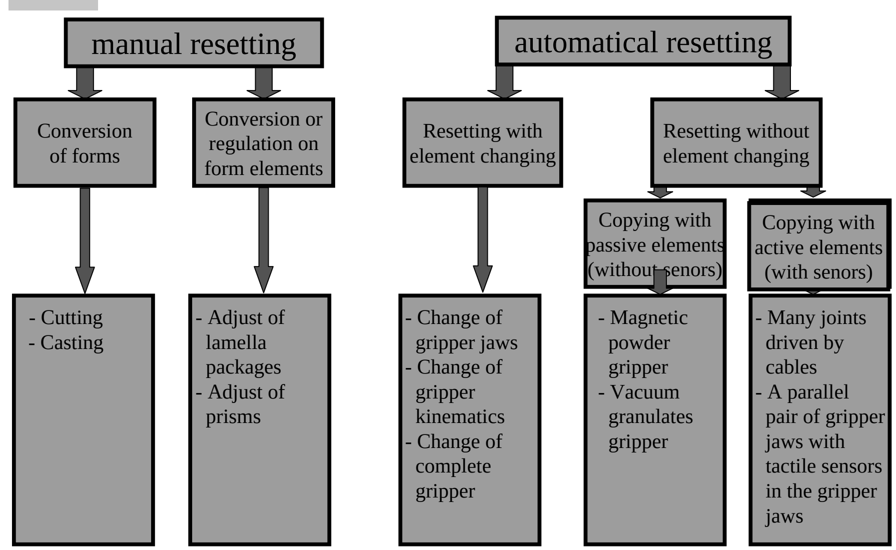
valuation criteration	pneumatic	hydraulic	electro-magnetic	electro-motor
High grab force	◐	●	○	◐
controllability	○	◐	◐	●
transfer of energy	◐	○	●	●
sensitiveness agains dirt	◐	●	○	◐
Maintenance	◐	◐	○	◐
Emergency stop behavior	◐	◐	○	○
Size	●	●	◐	◐
costs	●	◐	◐	○

● favorable ◐ middle ○ unfavorable

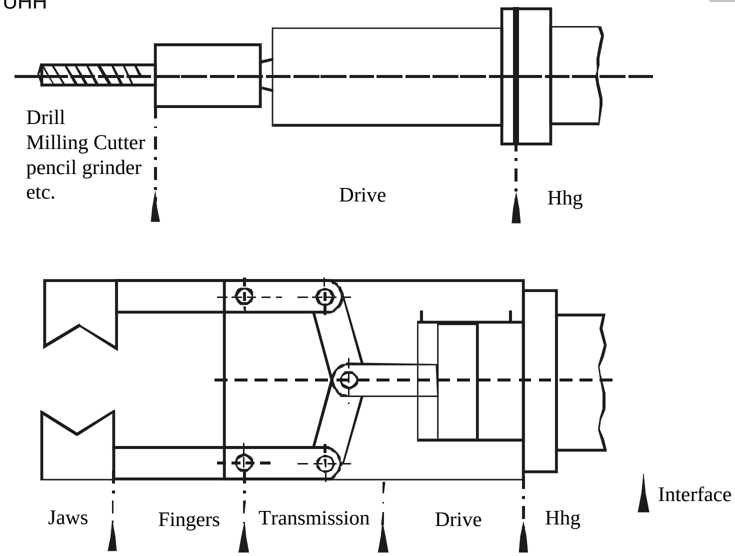
Advantages and disadvantages of different gripper actuators



Flexibility levels of gripper



Resetting procedure for gripper

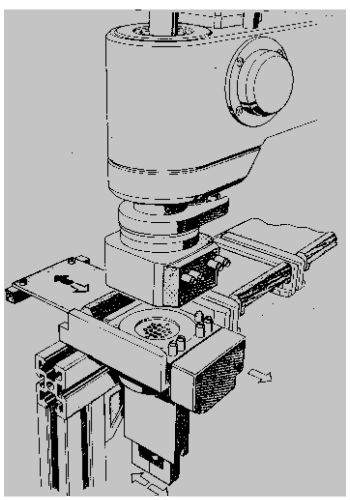


Interfaces of gripper

Aspects of selection of grippers

1. High power factor (large relation of grab strength to gripper mass)
2. Practicable mechanical and electrical interfaces for lever link and gripper jaws
3. The size spectrum of the grab objects adapted or adaptable gripper stroke/shift with acceptable closing and open- hours
4. Grab force protection with power failure
5. Small friction losses in transmissions and guidance
6. Possibilities for the kinematic supplement around wrist rotational and sliding axis (short-stroke)
7. Sensitive setting options for jaw movements and forces
8. As contactless query of the end positions of gripper jaws as possible
9. Integrated guidance of supply lines for energy and information
10. Insensitivity in relation to oscillations and impacts or absorption in the end positions
11. Great maintenance intervals
12. High service life

Aspects of selection of grippers



Gripper changing system

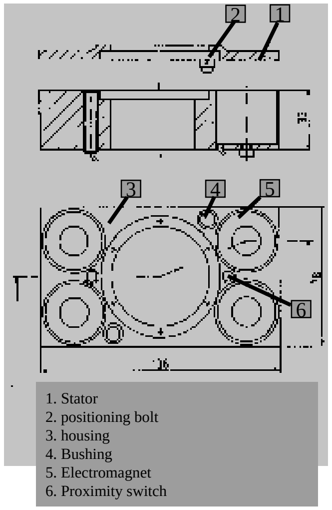
Operation types for gripper change devices

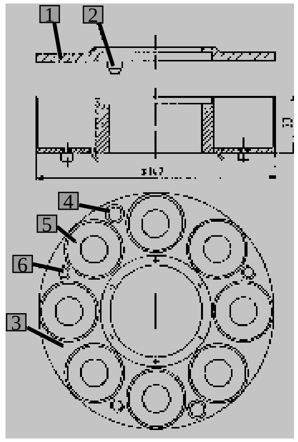
1. Self Actuation
   uses the movement possibilities of the handling equipment itself
   (easy, small; actuating forces by IR)

2. Internal Actuation
   by external drive in the handling equipment
   (large, heavy; only once necessary

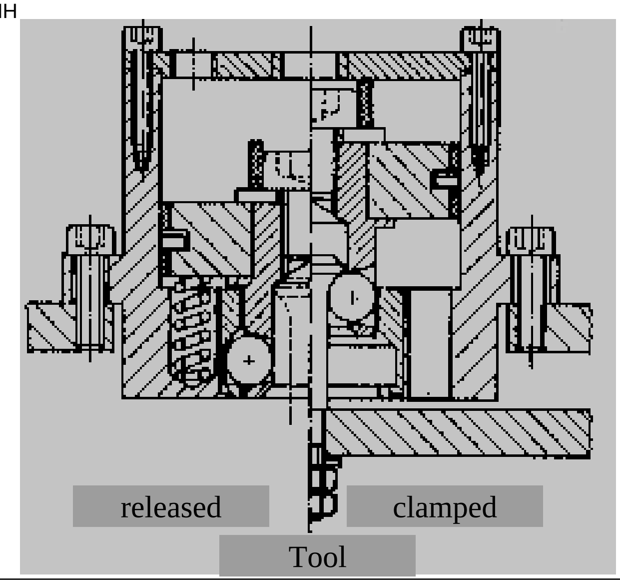
3. External Actuation
   actuator mounted to the magazine frame
   (high reliability, smallest influence on IR)

Operation types for gripper change devices

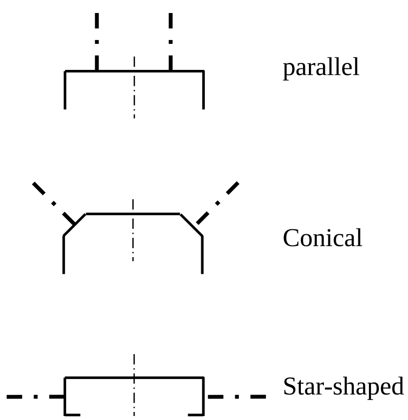


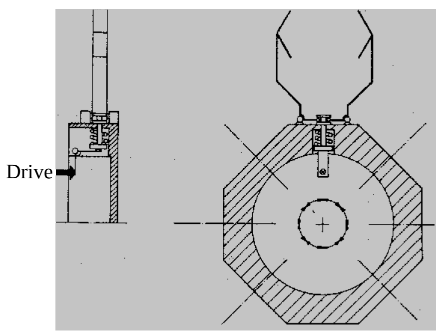


Change mechanism for permanent electromagnet



Support element with ball (sphere) adapter





Turret Gripper

Sensors for grippers

Switching Sensors

touching

Examples

- Switch for movement by mechanical one (e.g. limit switch)

contactless

Examples

- Attendance supervision and position test
- Light barriers
- Inductive proximity switches
- Capacitive proximity switches

Measuring sensors

touching

Examples

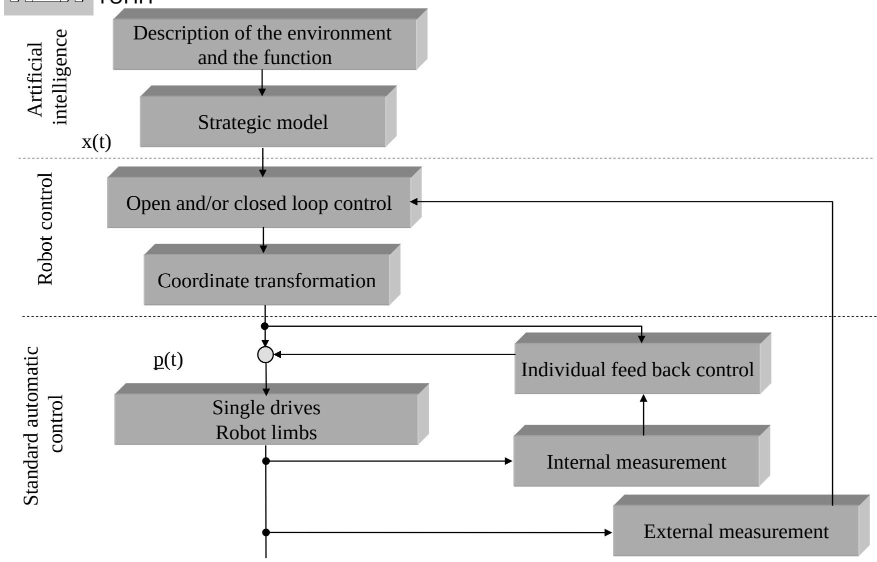
- Position measurement with linear potentiometer
- Gripper force measurement with strain gages
- Multidimensional force measurement by strain gages
- Pattern recognition by tactile surface sensors

contactless

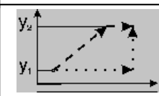
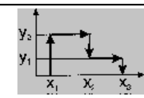
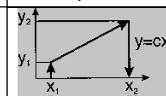
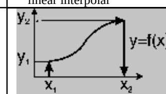
Examples

- Distance measurement by ultrasonic
- Distance measurement by laser triangulation
- Position measurement by video processing

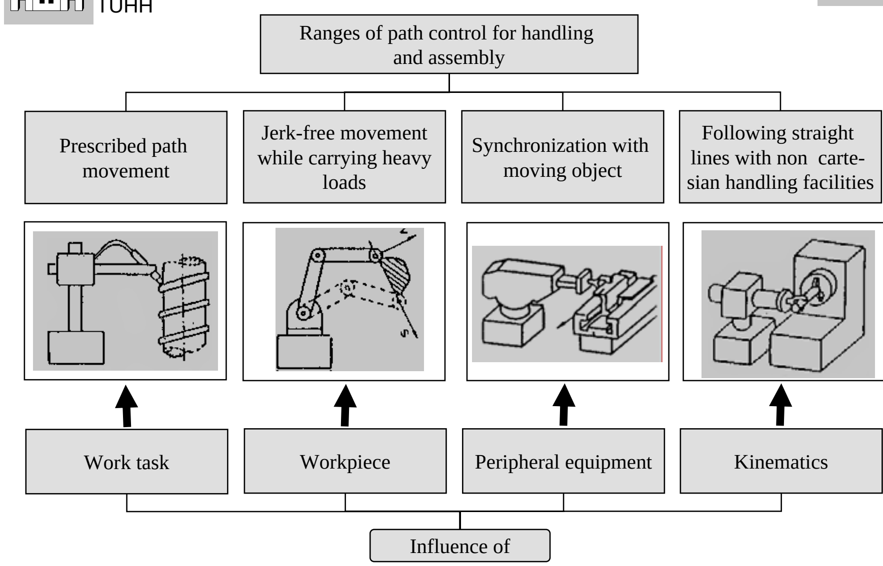
Sensors for Grippers



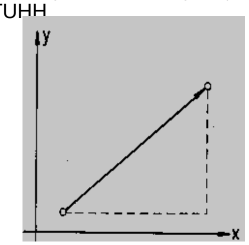
Function of robotic control

Control types	problem	tool	application
point-to-point control	 Path interpolator no necessary	During tool movement not in mesh	Drill Spotwelding
simple straight cut control	 Path interpolator no necessary	During tool movement in mesh	Rotation (cylindrical) Milling machines (parallel to axis)
straight cut control expanded	 with gear switching or linear interpolar	During tool movement in mesh	Rotation (conical) Milling machines (any straight lines
continuous path control	 Path interpolator (according to 2 order or higher degree equation	During tool movement in mesh	Rotation Milling machines flame cutting (any line)

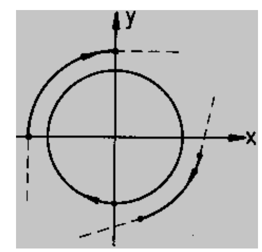
Control types



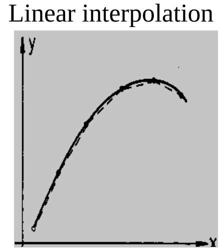
Field of application for control with flexible handling facilities



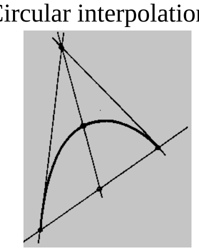
Linear interpolation



Circular interpolation

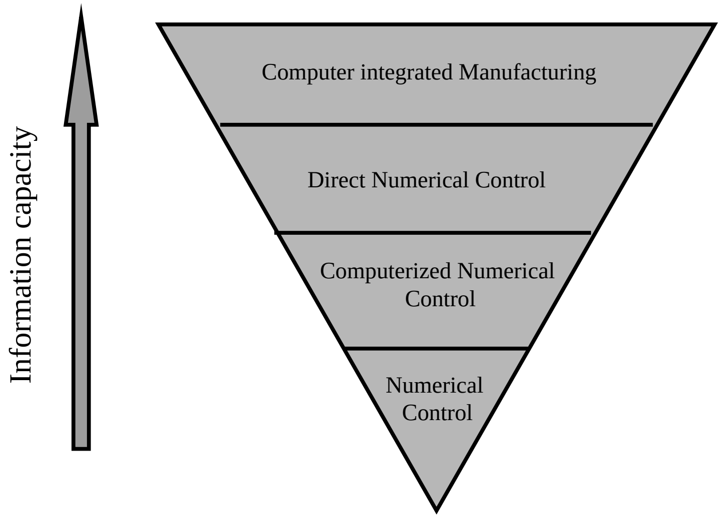


Approximation of a trajectory by linear interpolation



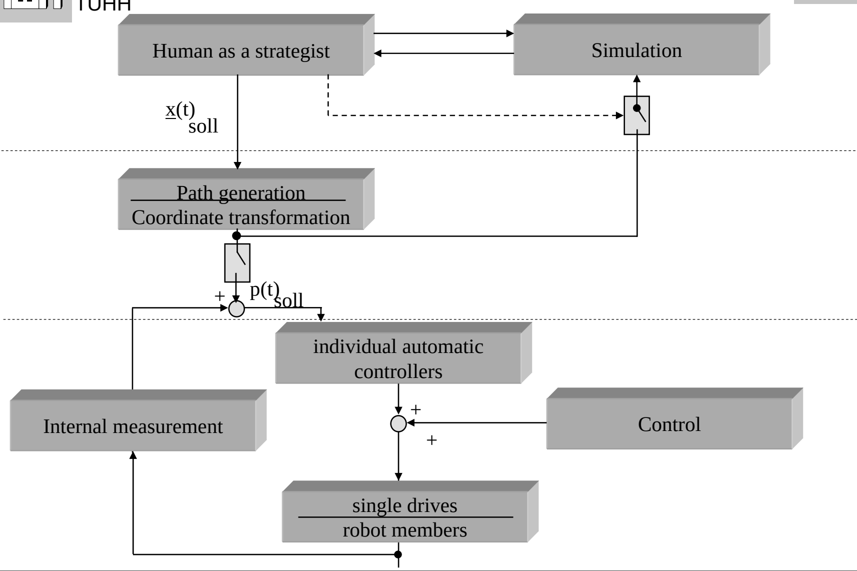
Parabolic interpolation

Interpolation method



Hierarchy of control

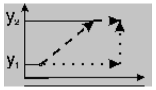
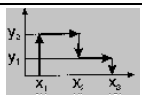
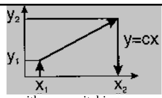
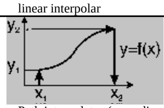
Beginn Abschnitt 4 „Steuerungen“



Present implementation of the control tasks

Direct programming	Indirect programming
Real robot system and system environment necessary	Computer model of robot system and model of the system are necessary
Manufacturing equipment is not available during programming	Programming in production planning department
Tests of the user program at the real system	Tests of the program through simulation
Limited accesses to operational informational systems	Full integration of operational information systems possible
Quality of the user programs depends on the experience of the programmer	Support of the programmer by intelligent computer-based aids

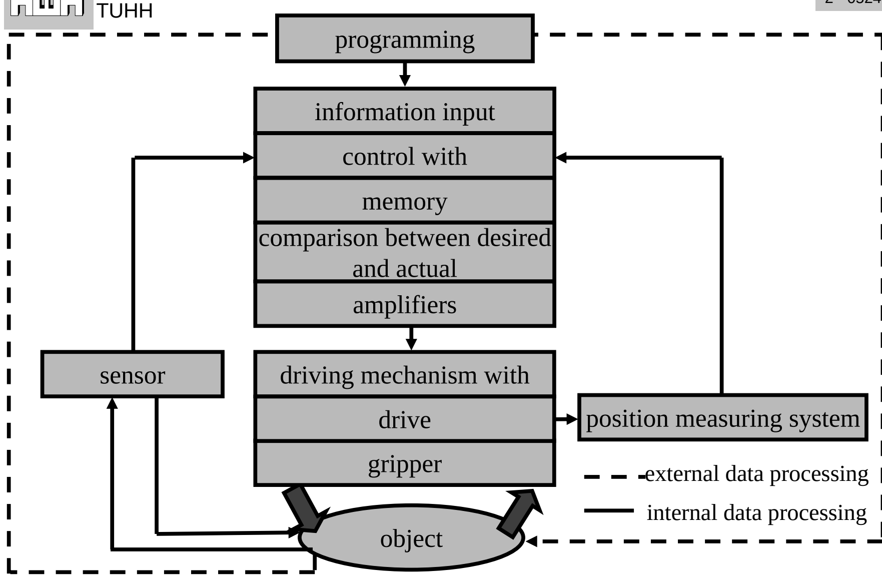
FEATURES OF DIRECT AND INDIRECT PROGRAMMING PROCEDURES

Control types	problem	tool	application
point-to-point control	 Path interpolator no necessary	During tool movement not in mesh	Drill Spotwelding
simple straight cut control	 Path interpolator no necessary	During tool movement in mesh	Rotation (cylindrical) Milling machines (parallel to axis)
straight cut control expanded	 with gear switching or linear interpolar	During tool movement in mesh	Rotation (conical) Milling machines (any straight lines
continuous path control	 Path interpolator (according to 2 order or higher degree equation	During tool movement in mesh	Rotation Milling machines flame cutting (any line)

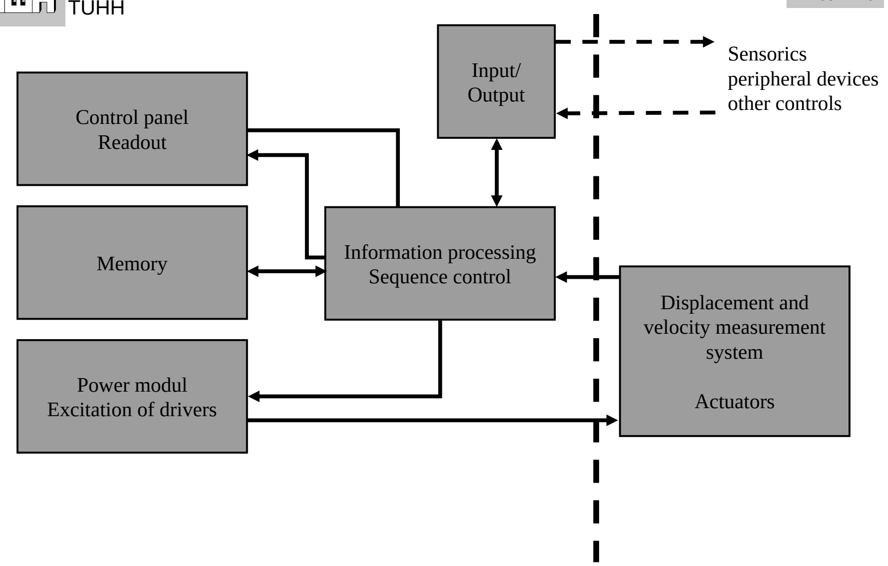
Control types

	Memory content	Function
Manual programming	10^2	handling
Teach-in	10^4	Welding, painting, coating, palletizing
Programming with programminglanguages	$>10^6$	assembling

Types of programming classified for application



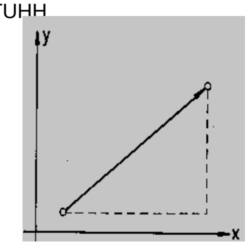
Internal and external data processing



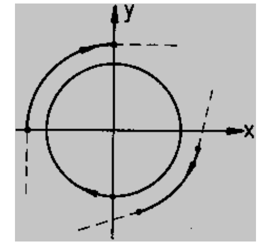
Control structure of industrial robot

motion measuring system:	functioning	application as
digital-incremental (rotational)	electromechanical : collector with brushes photoelectrical - glass rod with photodiode inductive - index plates of permanent magnet with Hall generator	synchro transmitters
digital-incremental (translational)	photoelectrical - grid scanned by photodiode	linear alarm unit
digital-absolute (rotational)	electro mechanical - coded disc with brushes photoelectrical- coded glass disc with photodiode inductive – index plates of permanent magnet with Hall generator	optical angle coder inductive angle coder
analog-absolute (rotational)	rotary potentiometer, inductive synchro transmitter	spiral potentiometer

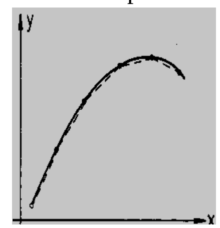
overview of robotic motion measuring systems



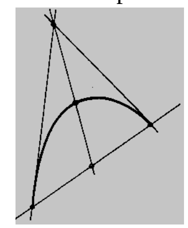
Linear interpolation



Circular interpolation

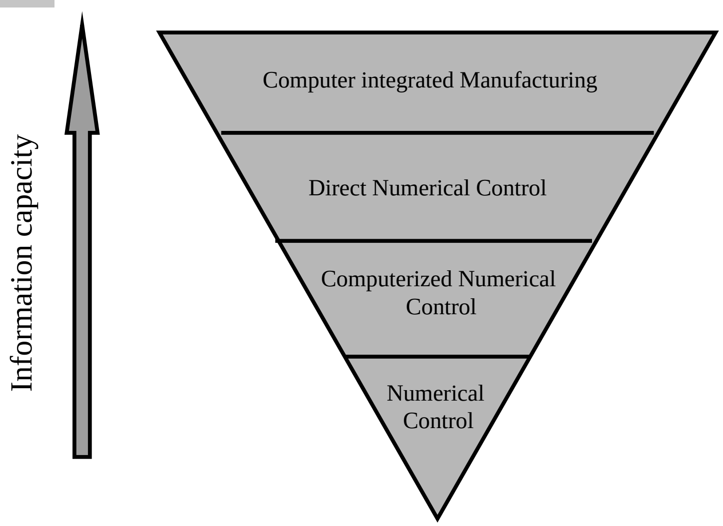


Approximation of a trajectory by linear interpolation



Parabolic interpolation

Interpolation method



Hierarchy of control

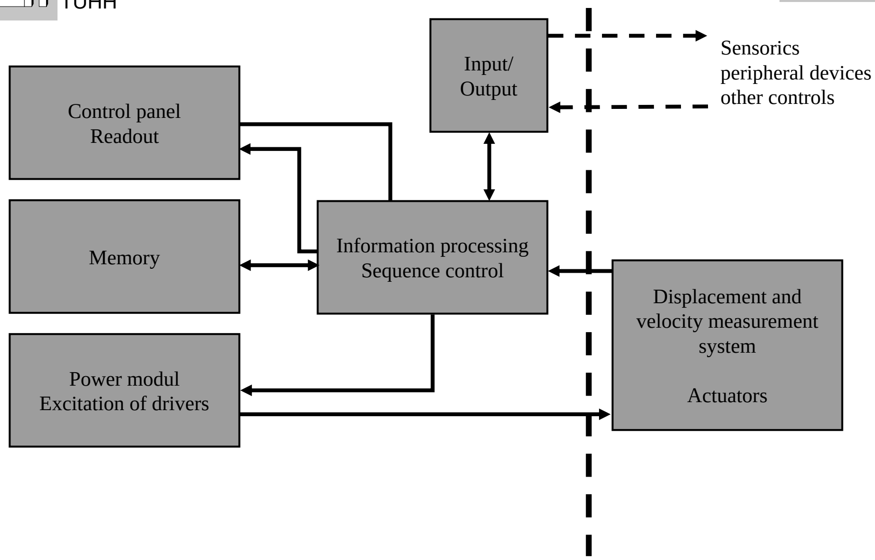
Basic functions

- NC program management
- NC data distribution

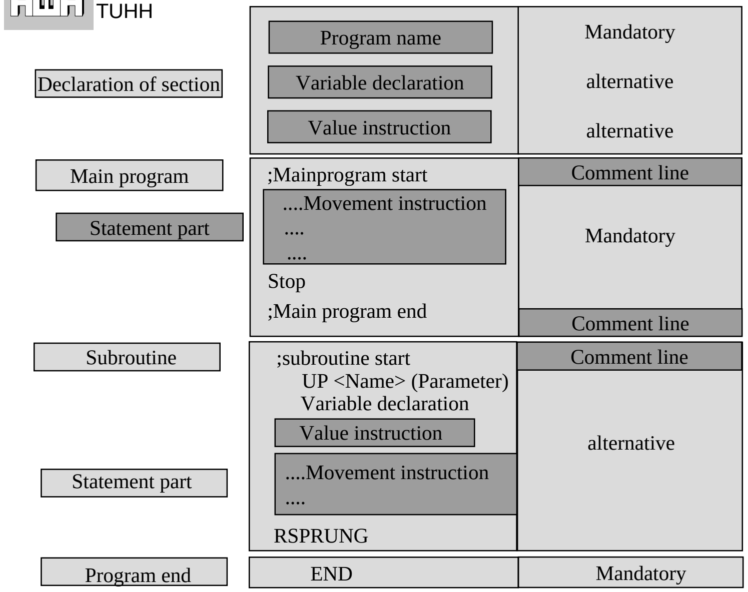
Extended functions

- NC data correction
- NC data creation
- Data input and processing
- Control functions for the flow of materials
- Subfunctions of the manufacturing control

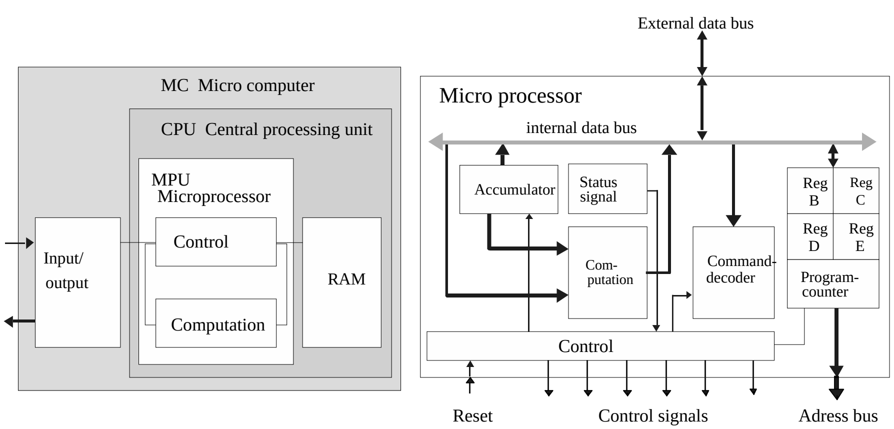
Functions of a DNC system



Control structure of industrial robot

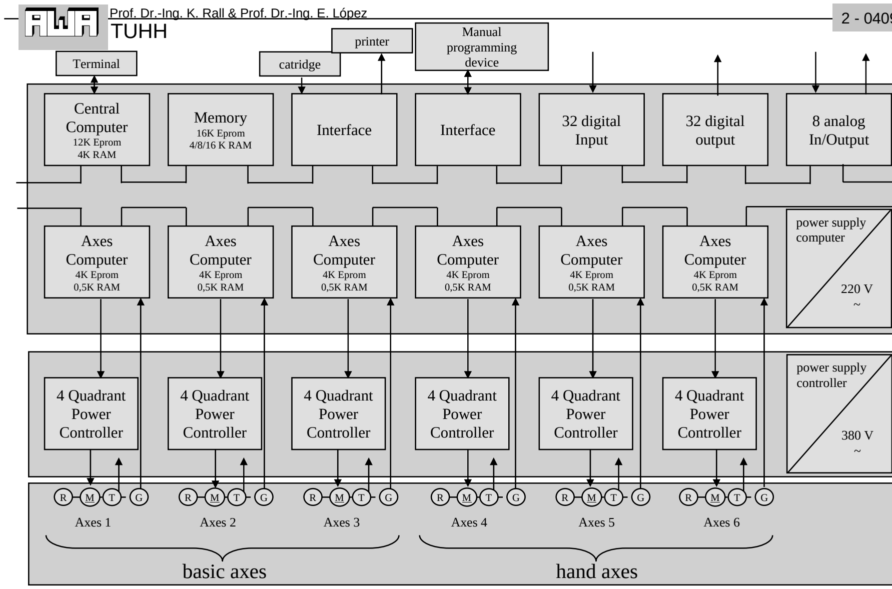


Program structure of BAPS



Construction Information flow

Micro computer



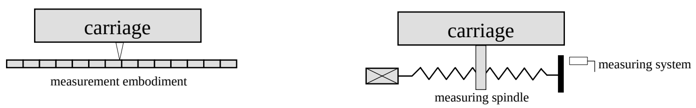
Block diagram of MPS085 control (Jungheinrich system)

According to the measurement principle:

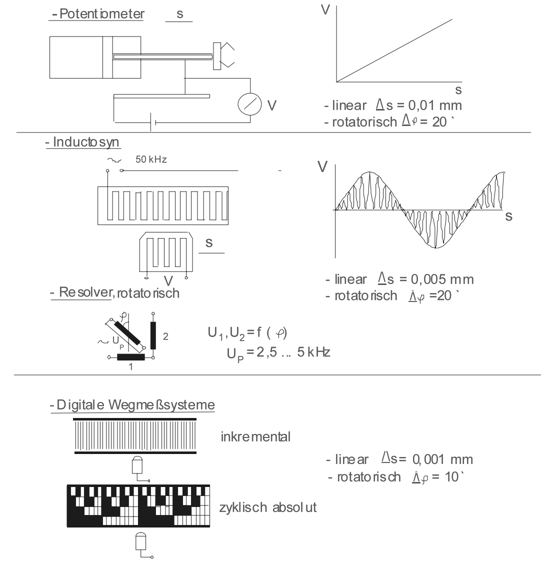
- **analog** — in a similar physical size (as resistance test)
  - after the determination of the measured value:
    - absolute measuring
    - ciclically absolute
- **digital**
  - absolute
  - incremental (as relative measurement)

According to the type mounting of the measuring system:

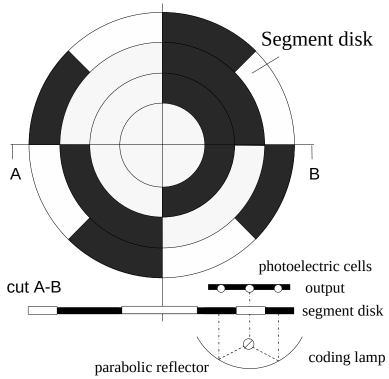
Direct-measuring | indirect-measuring

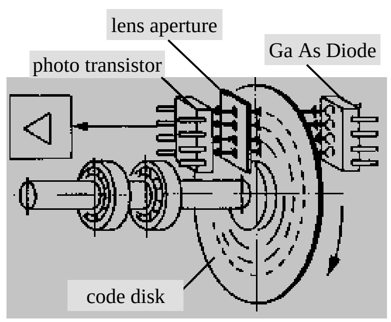


Classification of measuring systems

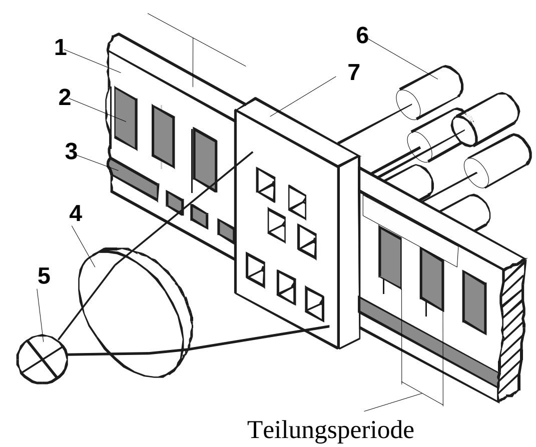


Measuring systems



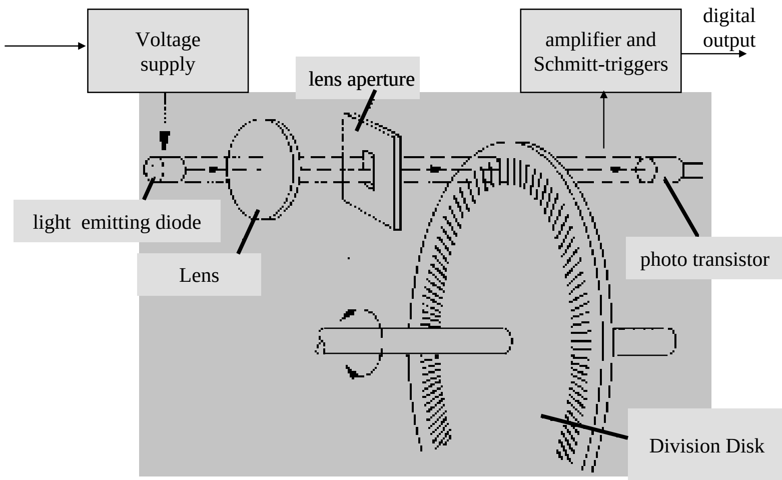


Segment disk

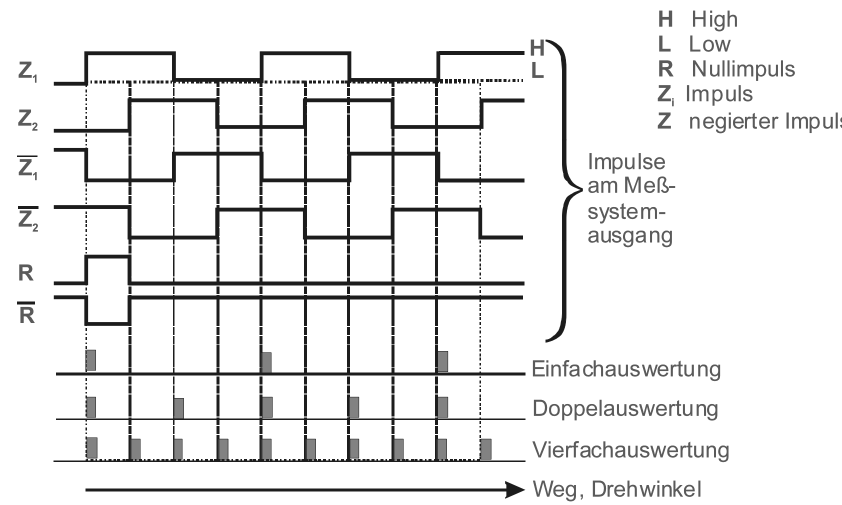


1 Glasmaßstab
2 Strichgitter
3 Spur mit Referenzmarken
4 Optik
5 Lichtquelle
6 Fotoelement
7 Abtastplatte

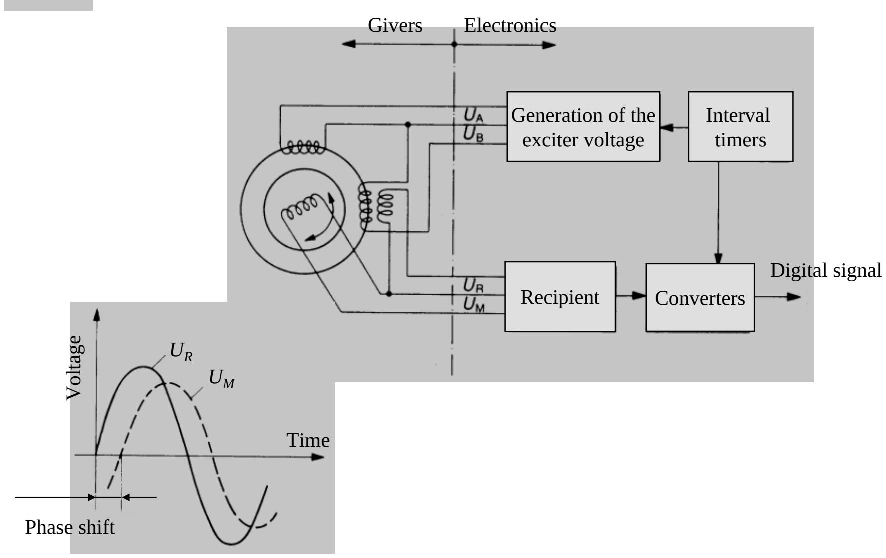
Prinzip der optischen Abtastung von Strichgittern



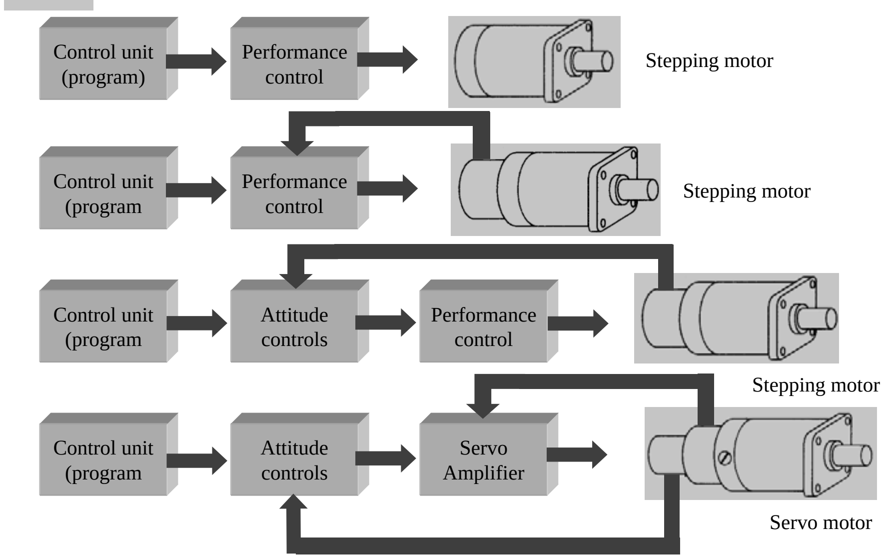
Principle of the incremental angular sensor



Impulsfolgen und deren Auswertung bei
einem mehrkanaligen Inkrementalgeber



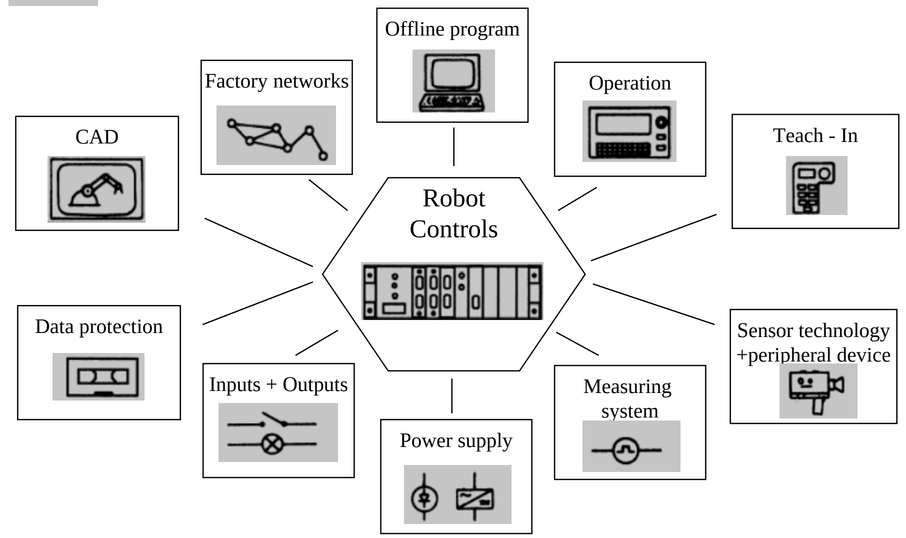
Principle pattern of a resolver



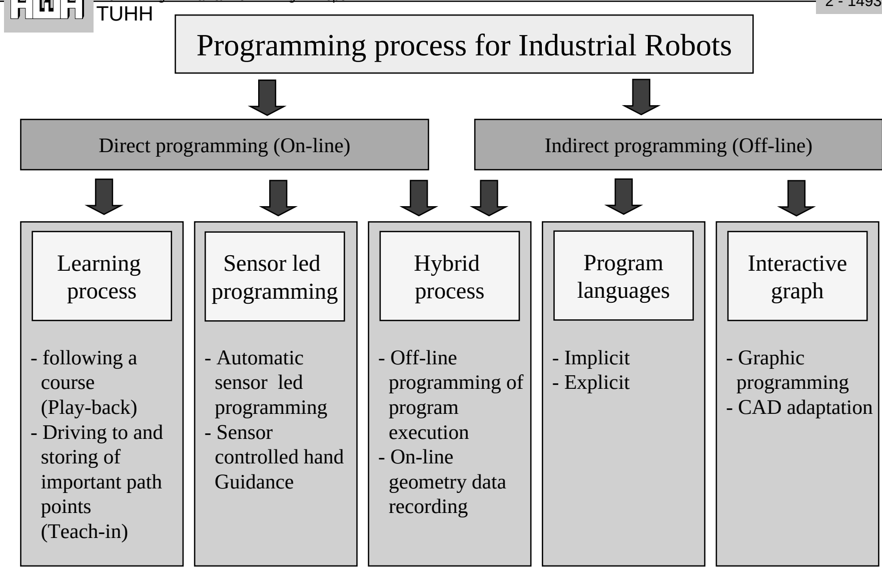
Position systems

	digital incremental measuring system	digital absolute measuring system	similar-absolute measuring system
Advantages	- small manufacture expenditure - simple comparators - not expensive - simple zero shift	- absolute measure-indicated - simple actual value-displays - stationary zero point - security against measuring/ transfer errors	- simple measuring system - simple zero point - simple comparators - absolute measuring procedure
Disadvantages	- no zero point - error propagation - procedure of point of reference	- expensive - complex - trouble-prone	- A-D-converter is necessary for difficult digital display

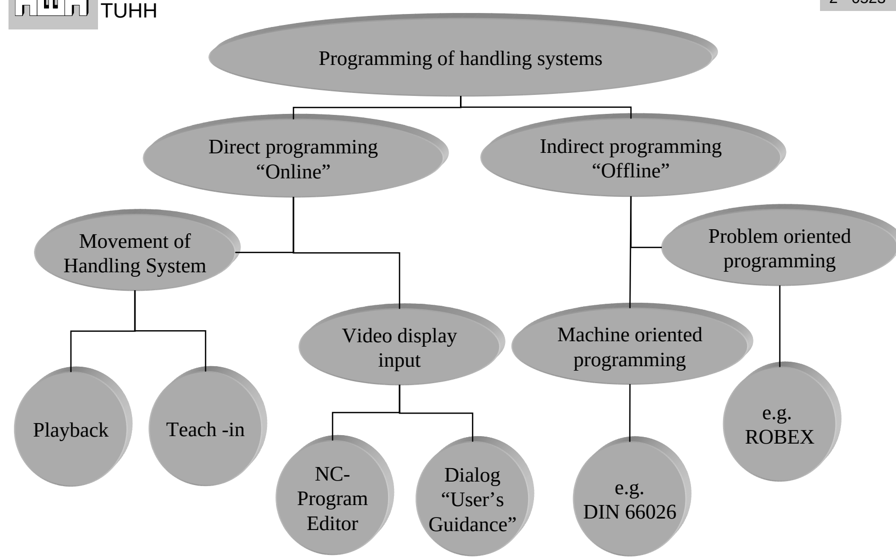
Measuring systems



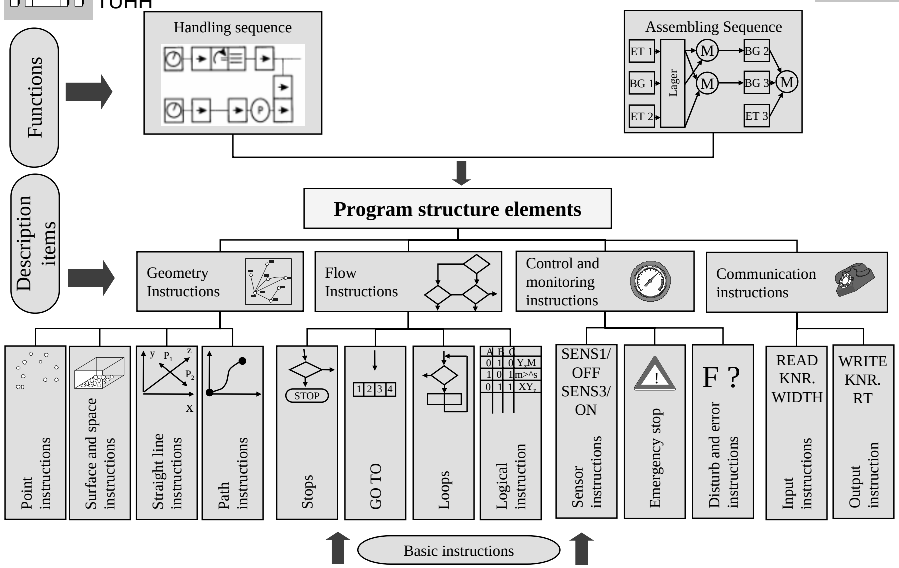
Control interfaces



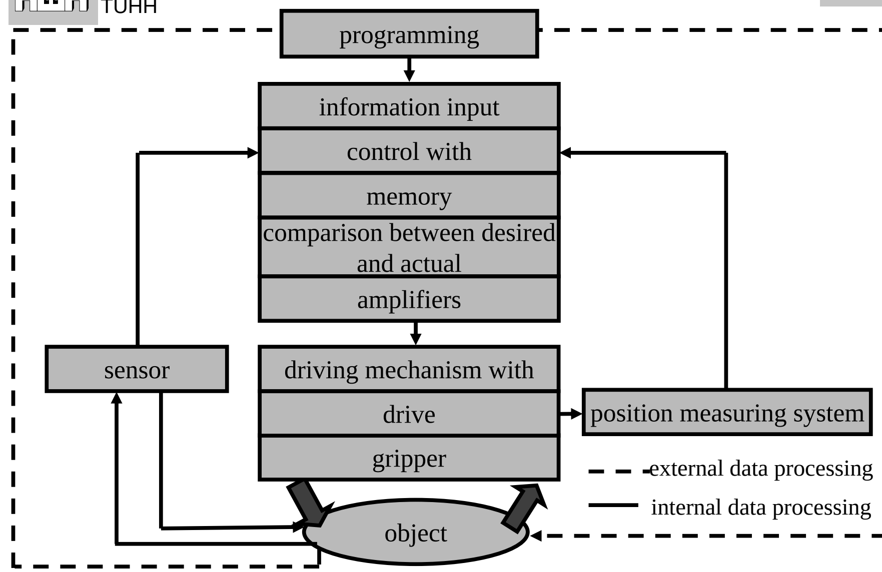
Programming process for Industrial Robots



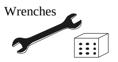
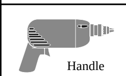
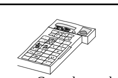
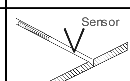
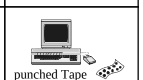
Programming process for Industrial Robots



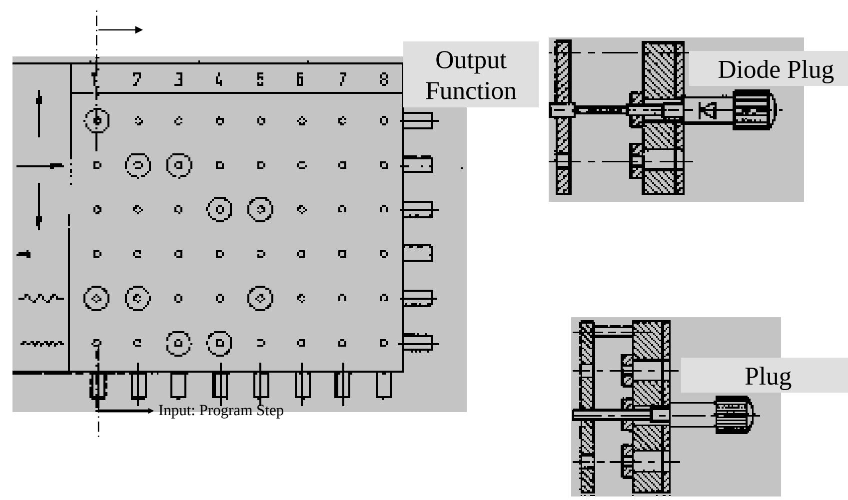
Program structure elements for IR



Internal and external data processing

	on-line			off-line	
	manual programming	Play back	Teach in	Sensor led	Computer aided
Principle	Wrenches 	 Handle	 Control console	Sensor 	 punched Tape
Advantages	no computer is necessary high accuracy is possible	quick and sample programming without programming languages	exact starting is possible procedure in Cartesians coordinate is possible Re-programming (update) in steps is also possible	hardly describable paths can be simply programmed Row material inaccuracies can be settled	Possible to simulate the program off-line partially uniform programming language simple correction no deadlock of the robots
Disadvantages	difficult re-programming	Process expertise is necessary Correction only possible by new program Difficulties in Optimization Large storage	locally programming stop the system	Sensor and time are necessary for entry	Exact information about tool Robot and surrounding field are necessary optimization locally Counting expenditure

Programming process for Industrial Robots



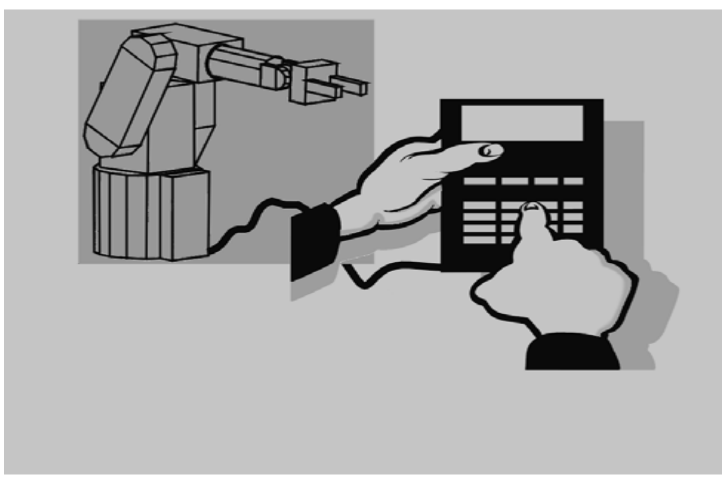
Cross Section Distributor

	Memory content	Function
Manual programming	10^2	handling
Teach-in	10^4	Welding, painting, coating, palletizing
Programming with programminglanguages	$>10^6$	assembling

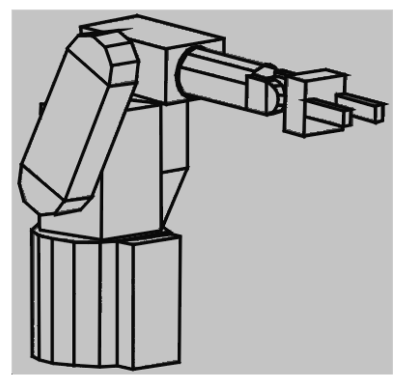
Types of programming classified for application

Command No.	Function
1	Horizontal forward rate
2	Horizontal feed rate
3	vertical lifting
4	vertical lifting
5	rotating clockwise left
6	rotating clockwise right
7	close gripper
8	Open gripper
9	gripper turn left
10	gripper turn right
11	gripper stroke off
12	gripper stroke on
13	Intermediate deadlock forwards
14	Intermediate deadlock backwards
15	End of Cycle
16	Reserve
17	Time 0.5 s
18	Time 1 s
19	Time 2 s
20	Time 4 s

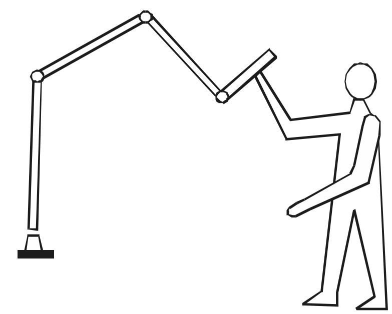
Punched card information input for IR



Teach-In Programming

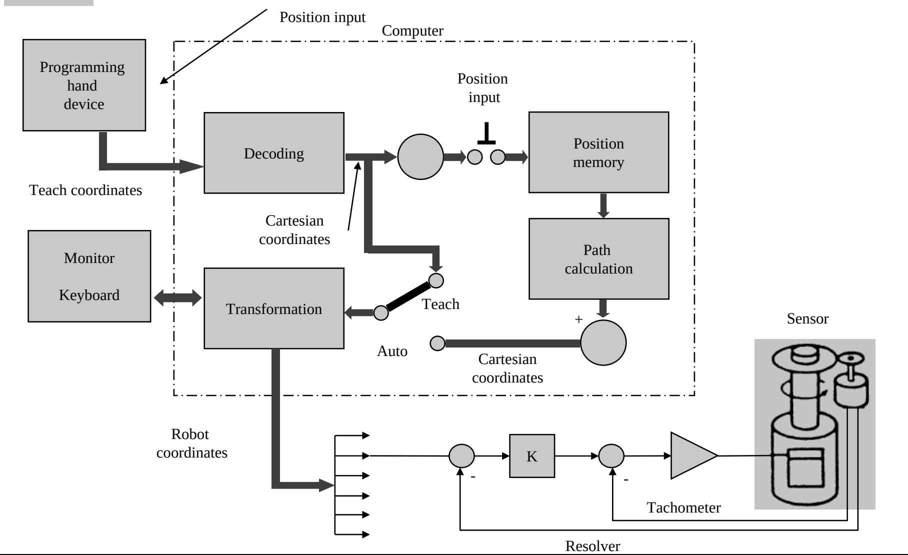


Roboter

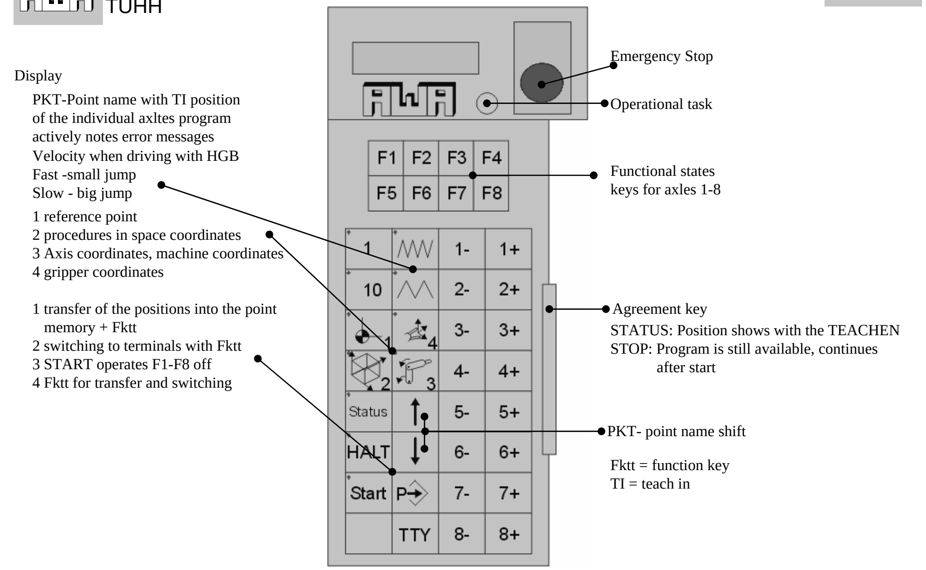


Program frame

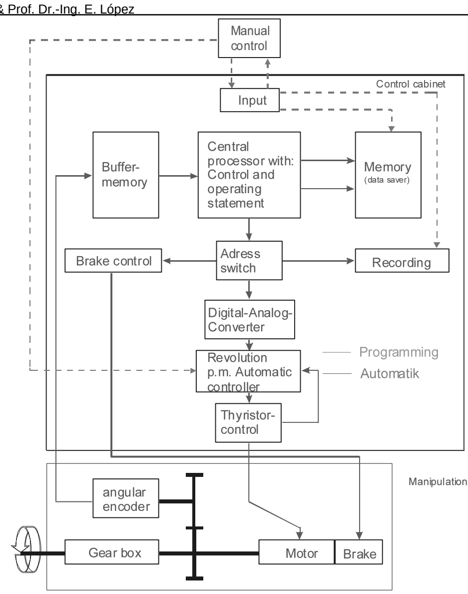
Play-back-programming



Teach-In programming system



Hand Control Panel



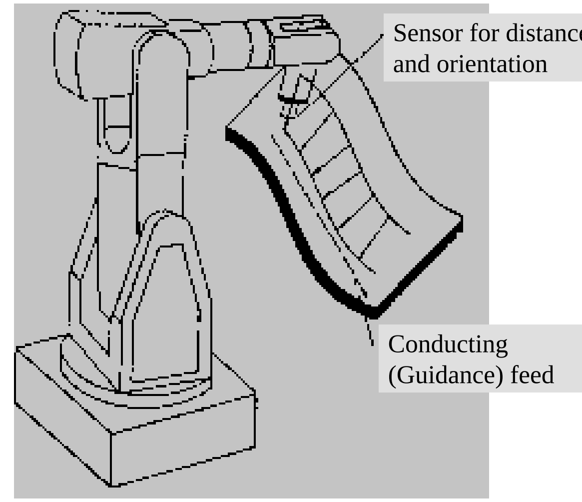
Program recording and replay with the teach in procedure

- Without deeper understanding for processes by the shop personnel, own work programs for running process can be created after a short training period;
- program correction can be carried out subseqently during the program test and require no new programming;
- introduction and deletion of individual statements as well as the modification of parameters are basic function of all considerable teach-in-systems;
- collision problems can be prevented to a large extent with this way of programming site;
- input of false coordinate is excluded by the derivative of the position of the robot axles.

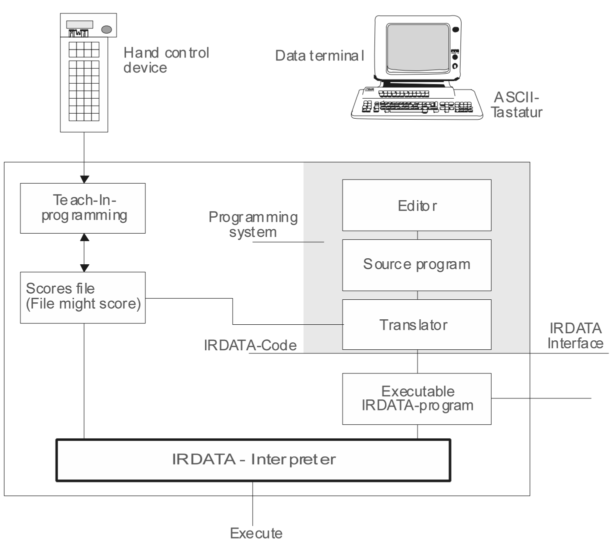
Advantages of teach-in-procedures

- In the case of small lot sizes,the proportionate programming times are economically no more justifiable;
- programming of complicated lines and the optimization of complex processing steps are time-consuming processes, those presuppose a great intuition of the programmer;
- the common programming of the pathes and of the frame program achieves in large sized user programs with conditioned branches a degree of complexity, wich is nearly unmanageable in most cases;
- a separation of the movement programming and the creation of the program framework, i. e. the logical program flow function is meaningful only in those cases if both systems are parts of an integrated system, so that no problems can occur with a subsequent program correction.

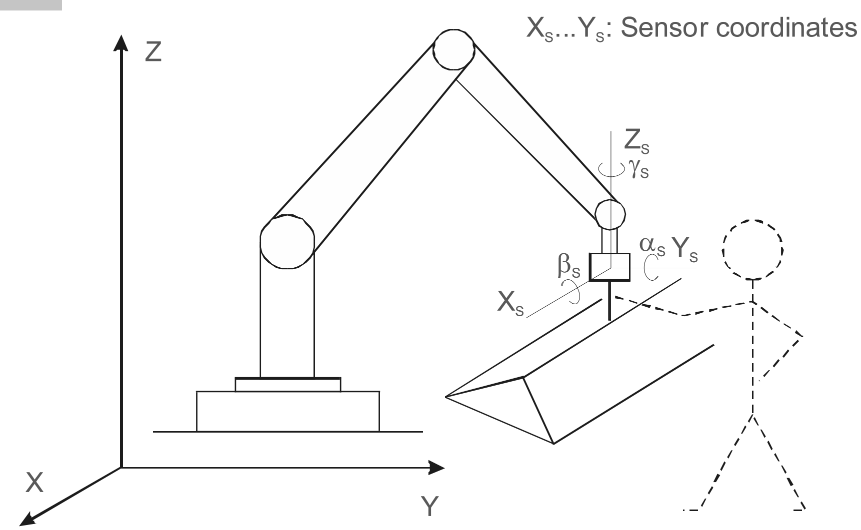
Disadvantages of teach-in-procedures



Automatic sensor-led programming



Programming system



Pilot actuated hand guidance

programming system

EDITOR
Creation of the work program

Compiler
Creation of an control independent user program

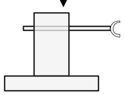
Postprocessor
Control specific user program

Control

Data bases
- Description of the handling equipment
- Environmental description

Data bases
- Description of the control

control system

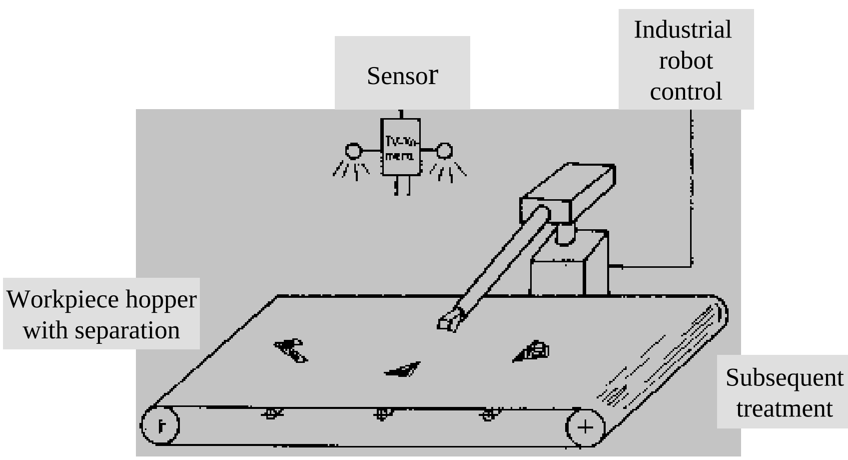


Handling equipment

Components of an external programming system

Advantages	Disadvantages
- Reduction of the idle times of robot and peripheral equipment	- Complex system configuration
- comfortable program preparation because of computer aid and higher programming languages	- Missing standardized interfaces
- easy alteration of programs	- Problems due to variety of IR-controls
- good documentation possible	- Lacking of clearness
- Subroutine technique; program jumps possible	
- easy alteration of programs	
- simple inclusion of external data inputs	

Pros and cons. of external programming



Arrangement of equipment with the storage of pictures

Direct programming	Indirect programming
Real robot system and system environment necessary	Computer model of robot system and model of the system are necessary
Manufacturing equipment is not available during programming	Programming in production planning department
Tests of the user program at the real system	Tests of the program through simulation
Limited accesses to operational informational systems	Full integration of operational information systems possible
Quality of the user programs depends on the experience of the programmer	Support of the programmer by intelligent computer-based aids

Features of direct and indirect programming procedures

Programming languages of industrial robot

Elementary
movement-oriented
Program flow-oriented

- direct movement instruction
- elementary program flow functions

World-model-oriented
Job-oriented
problem-oriented

- descriptions of movement function
- simple and composed description of program flow
- description of robot geometry
- description of work space

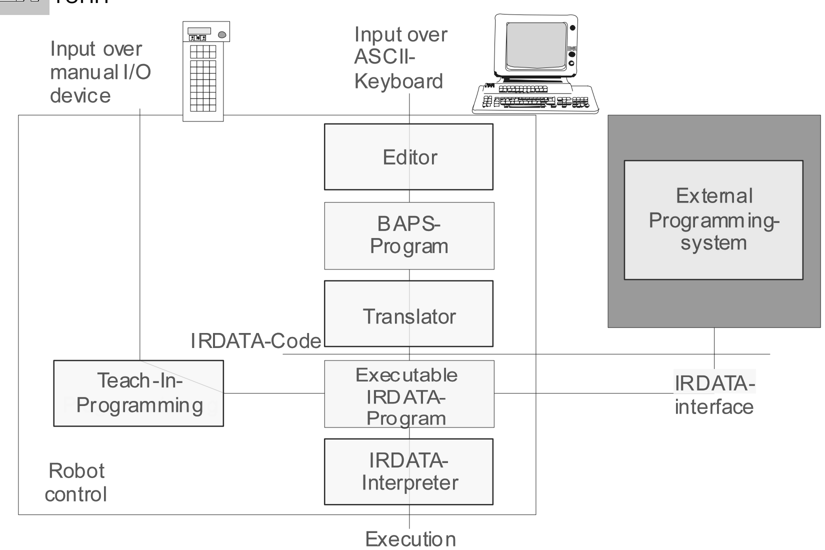
Language structure of industrial robot

Main program declaration	program end	first statement of a program last statement of a program
Subroutine declaration	UP name RSPRUNG	first statement of a program last statement of a program
Movement instruction	go trough point... to point ... shift linear PTP	absolute moving points without delay points exactly start incremental moving points without delay points exacly start linear interpolation point to point proceed
Repetition	WDH number MAL WDH_end	beginning of the repetiton with repetition number end of the repetition
Caused statement	if condition then statement else statement	 condition fulfilld condition not fulfilld
Branch instruction Delay and stop	bransch label WAIT value WAIT UNTIL condition PAUSE stop	 retention time in 0,1 s waiting for a condition to be fulfilled program stops, restart necessarily end of program
Definition input/output	input: X=name output: y=name	X,Y number of the input or output
Value assignment Velocity/acceleration	variable=value V=value A=value V_PTP = value	i.e. ventil =1 (valve on) velocity in mm/s acceleration in mm/s² velocity für PTP in %
Arithmetic, logical and comparison	+,-,*,/, und, oder, nicht <, >, <=, >=, <>, =	
Comment	;	

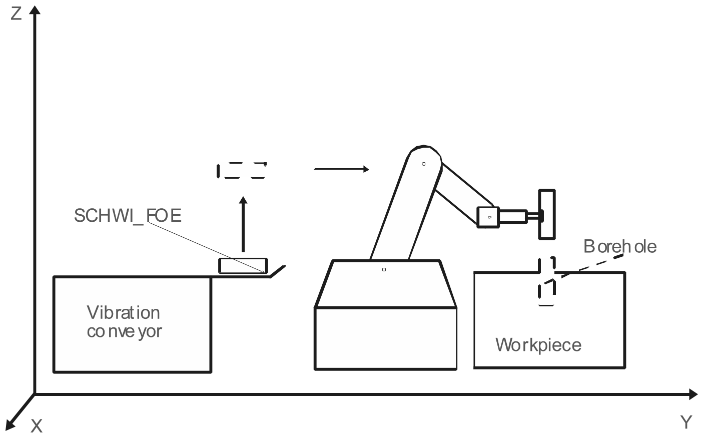
Basic elements of the language BAPS

Declaration of section	Program name Variable declaration Value instruction	Mandatory alternative alternative
Main program Statement part	;Mainprogram start ....Movement instruction .... Stop ;Main program end	Comment line Mandatory Comment line
Subroutine Statement part	;subroutine start UP <Name> (Parameter) Variable declaration Value instruction ....Movement instruction .... RSPRUNG	Comment line alternative
Program end	END	Mandatory

Program structure of BAPS



BAPS programming system



SCHWI_FOE Teached grab point at the vibration conveyor

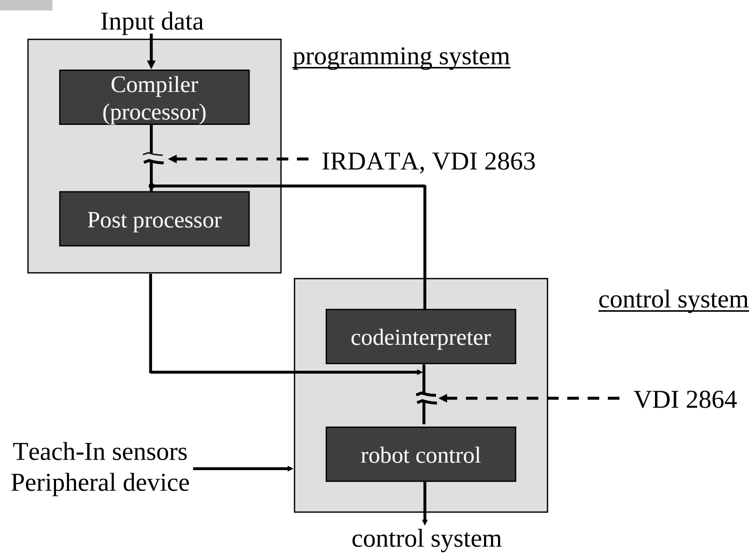
BOHRUNG Teached assembly point

Assembly task

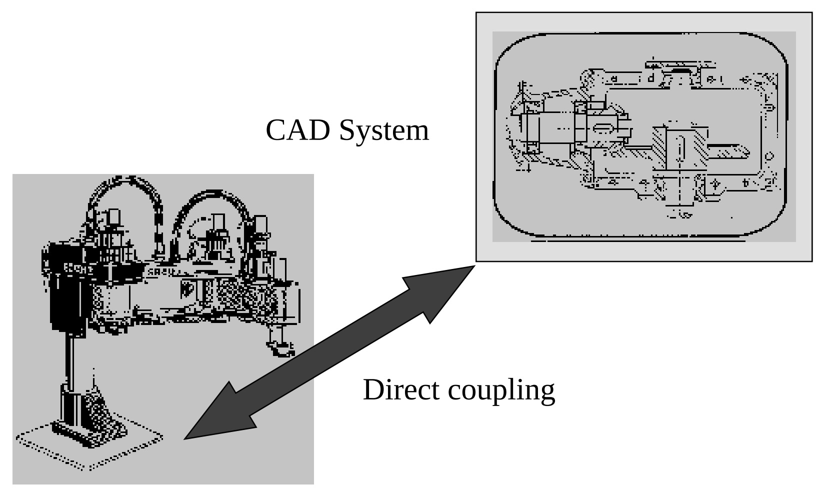

```
PROGRAM  MONTAGE
   INPUT 9=TAKEN                          ;Binary input  sensor at clamp 9=conveyor
   INPUT 13 = GRIPPER_ON                  ;Exit signal on clamp 13
     DISTANCE = (0,0,100)                 ;Difference vector with Z=100
     DRIVE TO OSC_CONV                    ;Arm movement to the osc. conveyor
     GRIPPER_ON = 0                       ;Close the gripper
     DRIVE TO OSC_CONV+DISTANCE           ;Move to a position above the conveyor
     WHEN TAKEN = 0 THEN                  ;The readout on the display:
            PAUSE                         „PART not taken“ (display text)
                                          ;if the pieve was not taken
     DRIVE OVER DRILL+DISTANCE            ;Reaching the insertion position
     DRIVE LINEAR WITH V=10 TO DRILL      ;Insert the pin with small velocity
     GRIPPER_ON = 1                       ;Open the gripper
     WAIT 0.5                             ;wait for 0.5 sec

   DRIVE OVER DRILL+DISTANCE TO OSC_CONV*DISTANCE
END
```

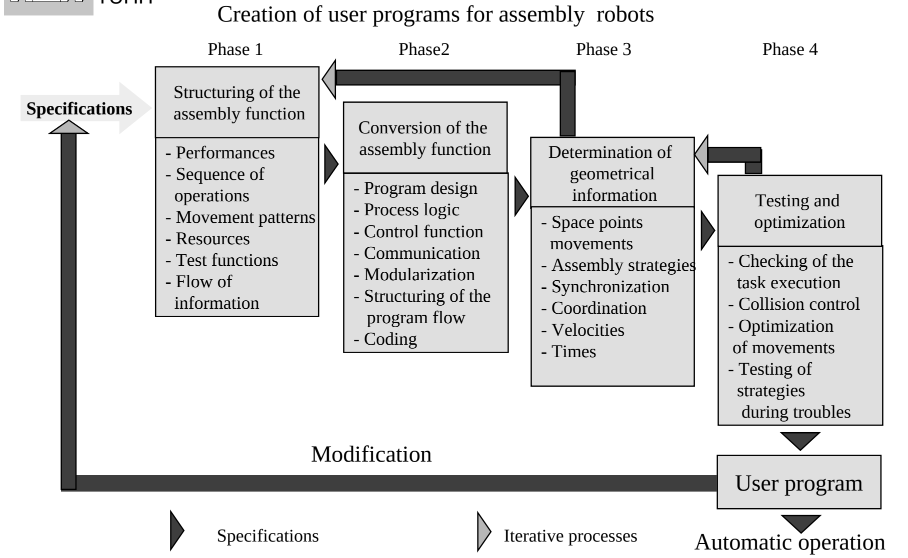
Example of a program in BAPS



Interfaces for external programming systems



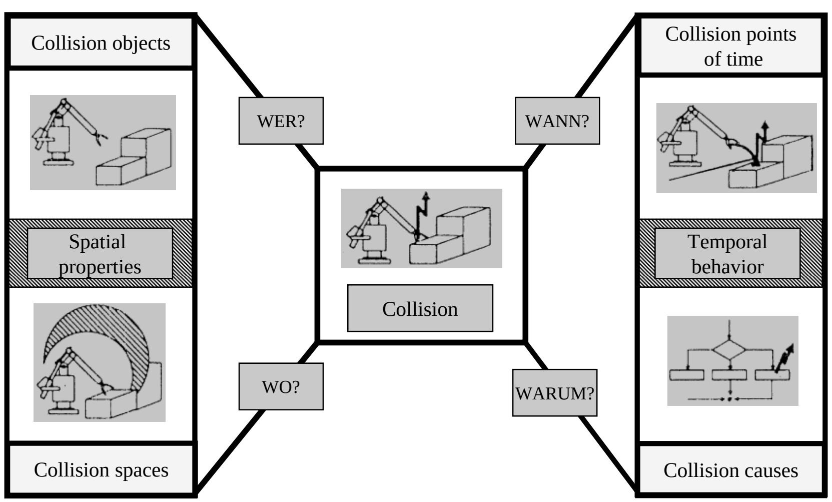
Automatic generation of a robot program from CAD data



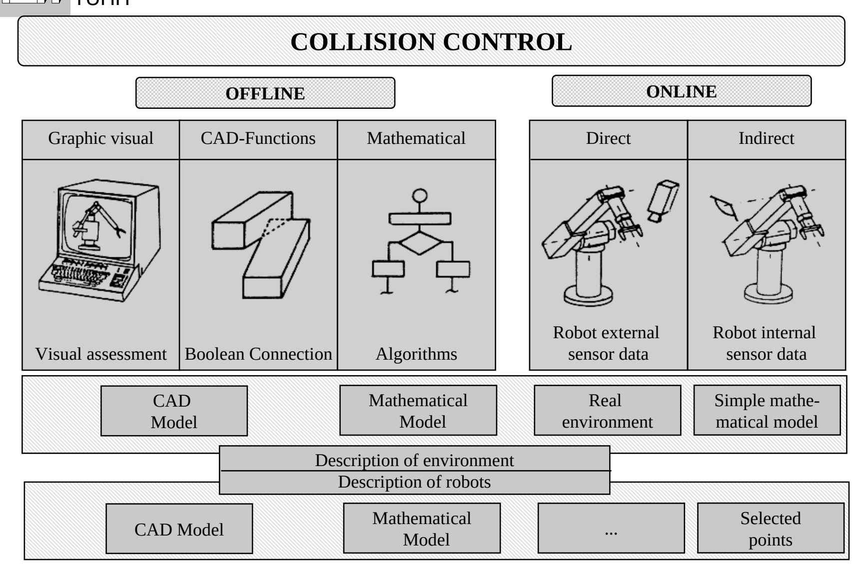
Methodology for the programming of assembly robots

Collision is defined as the temporal and spatial unintentional crash of 2 bodies, whereby at the moment of meeting at least one body has a kinetic energy different than zero

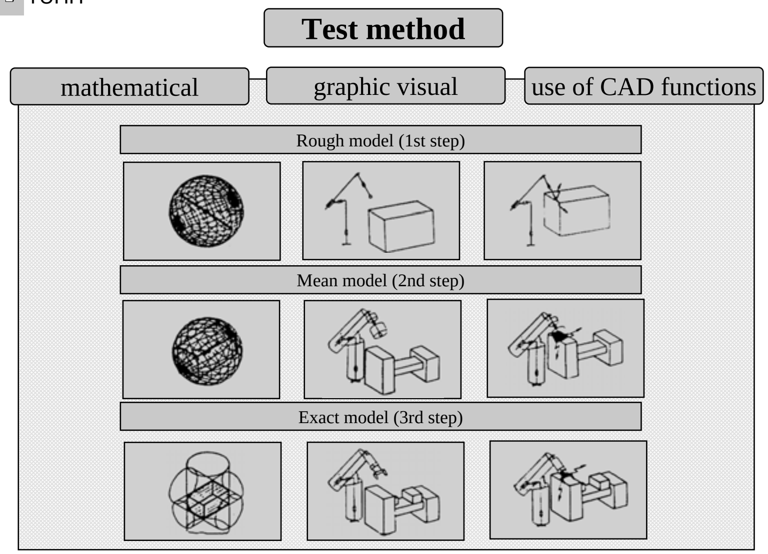
Collision



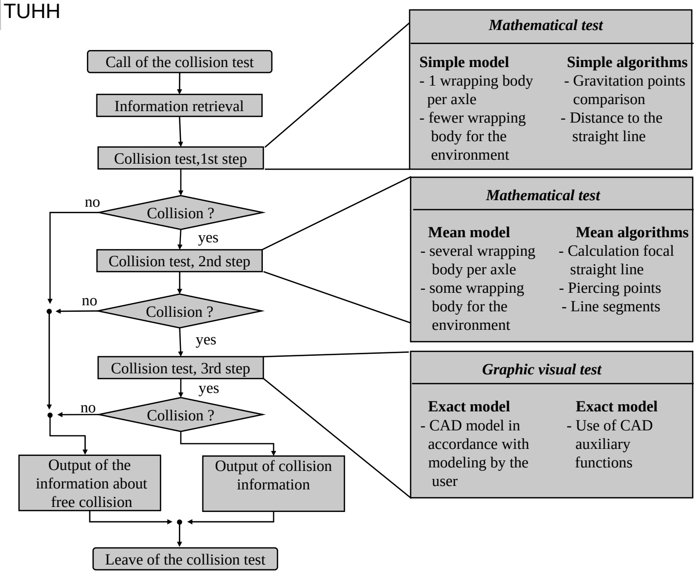
Variables which influence collisions



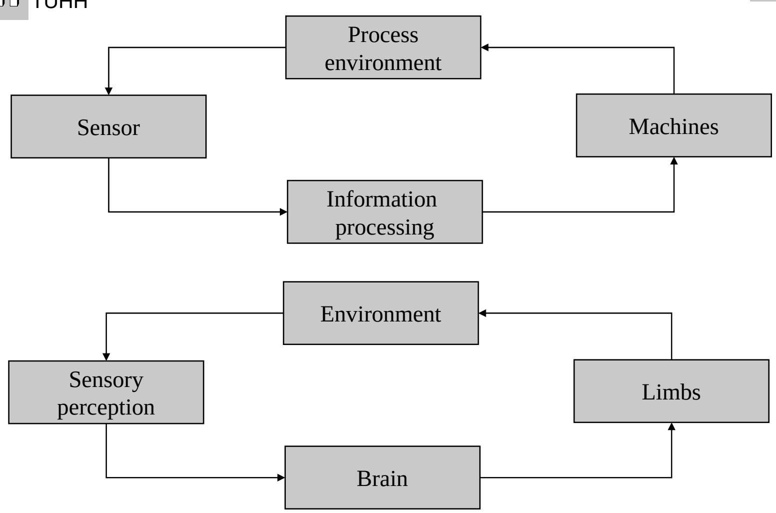
Methods of the collision control



Methods for the collision test during off-line programming



Strategy for an automatic collision test



Analogy of the automatic control loops of industry processes and human

Sensor system = sensor + transducer + amplifier (+ evaluation)

Problems in production, for the direct application of sensors:

1. Production runs are not always 100% automizable ⟶ the remainder workstation are unsatisfactory for humans, since one-sided load of humans through check or difficult assembly work.
2. Not sufficiently flexible devices are for automation for the order.
3. The actual process,but also the peripheral mechanism do not only have to be automated.

From this result 3 principal reasons for the use of sensors with assembling and handling functions:

1. Monitoring of the process variables (forces, length etc.), around process errors if necessary promptly to detect.
2. Log (and analysing) from process variables, over from it trends´s able to derive
3. Correct the process variables and a monitoring of the correction.

Sensors

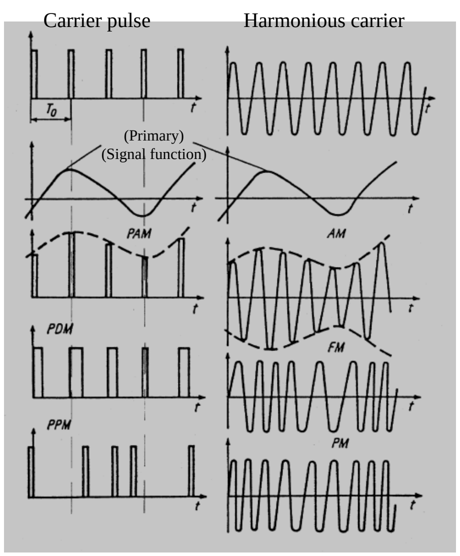
SENSOR

Receivers	Transducers	Amplifiers	Analysis
- with contact - without contact	- Analog-Digital - Digital-Analog - Pulse count	- Linear - Nonlinear	- Measurement - result

Subsystems of a sensor

motion measuring system:	functioning	application as
digital-incremental (rotational)	electromechanical : collector with brushes photoelectrical - glass rod with photodiode inductive - index plates of permanent magnet with Hall generator	synchro transmitters
digital-incremental (translational)	photoelectrical - grid scanned by photodiode	linear alarm unit
digital-absolute (rotational)	electro mechanical - coded disc with brushes photoelectrical coded glass disc with photodiode inductive – index plates of permanent magnet with Hall generator	optical angle coder inductive angle coder
analog-absolute (rotational)	rotary potentiometer, inductive synchro transmitter	spiral potentiometer

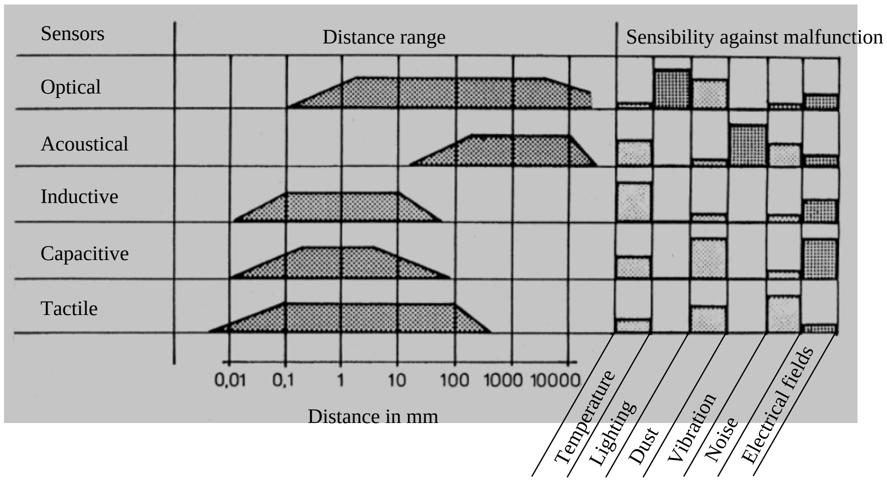
Overview of robotic motion measuring systems



Modulation procedure

Amplitude analog	Digital	Frequency-analog
Measured signal is transferred to an amplitude value Disturbances of the measured signal by electrical interference Multiplexer, filter, sample-hold-circuit and analog/digital converter required Cycle-time of the sensor-sampling will be strongly influenced by the multiplexer sample-hold-circuit and A/D-converter Parallel instrumentation of multiple signal-channels is very expensive Central multiplexer and A/D-converter diminish the reliability of the system	Measured value is transferred to a data-work of a certain length Disturbance-free transfer via data-protection using suitable codes Greater bandwidth needed Measured signal in computer-compatible form available Digitally optimized system concept Easier connection of all digital system components to the computer via bus Process disturbances of the bus lead to failure of the complete system Restrictions of the dynamic properties	Measured value will be converted into a frequency and/or period-length of pulse-duration Precise and non-sensitive to disturbance signal transfer Offset voltages and –flows cause no loss of accuracy Simple and cheap digitizing using a counter circuit There can be a frequency/digital converter assigned to every measuring channel Low-cost instrumentation of multiple parallel signal-channels Extended reliability Restricted dynamic properties

Properties of the different signal representation methods



Distance-measuring systems for Industrial Robots

Sensor without contact and tactile sensors

Recognition and correction of position errors
- Assembly (putting parts together, joining)
- Finding of bore holes
- Recognition of surfaces and edges
- Positioning of the gripper to the object
- Getting a workpiece out of the bunker-storage

Carrying out of simple movements
- Inserting of a pin into a bore hole
- Latching cranks and joints
- Adjustment
- Testing the movability of assembled modules

Recognition of sequence-disturbances
- Collisions
- Overloading
- Errors of the contour of the workpiece

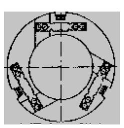
Making programming easier
- Tracking-control for following edges
- Force-reduction by path-programming
- Gripping-force control

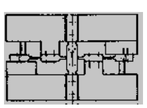
Recognition and classification of workpieces
- Recognition of 3-dimensional patterns
- Organize
- Qualification of weight

Possibilities of applications for Industrial Robots with tactile sensors

tactile sensors

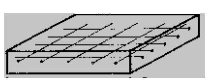
- measuring of single variables (force, moment, route,...)
  - strain gages
  - piezo-sensor, pneumatic converters, capacitive sensors, potentiometers



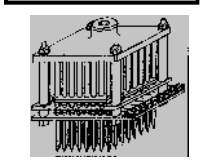


automated insertion- and assembly processes

- pattern recognition
  - analog position- and composition measuring
    - 2-dimensional
      - pressure-sensitive plastics-matrix
    - 3-dimensional
      - inductive pin-matrix



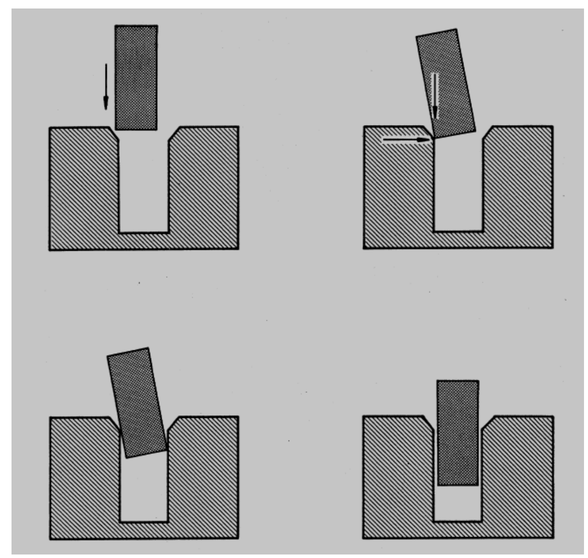
embedded threads



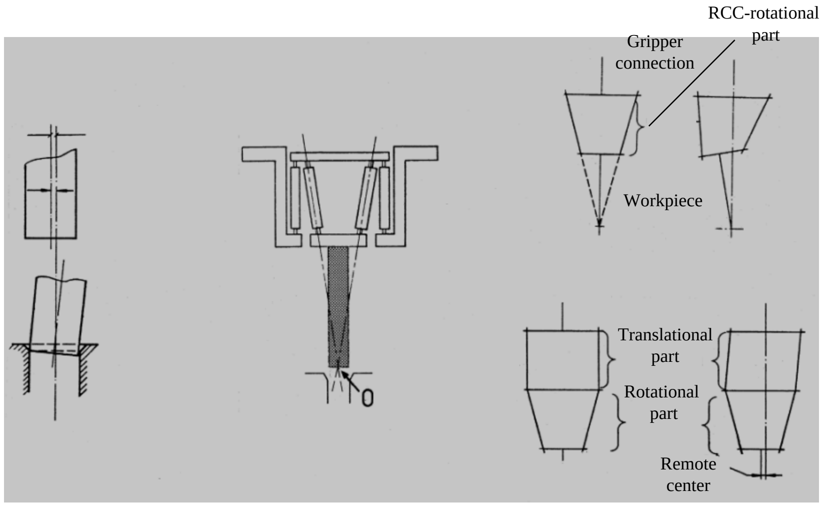
inductive sensor-pins

position-recognition in automated manufacturing and assembly installations

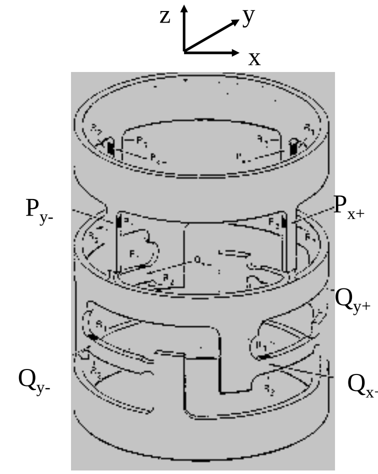
constructions of tactile sensors



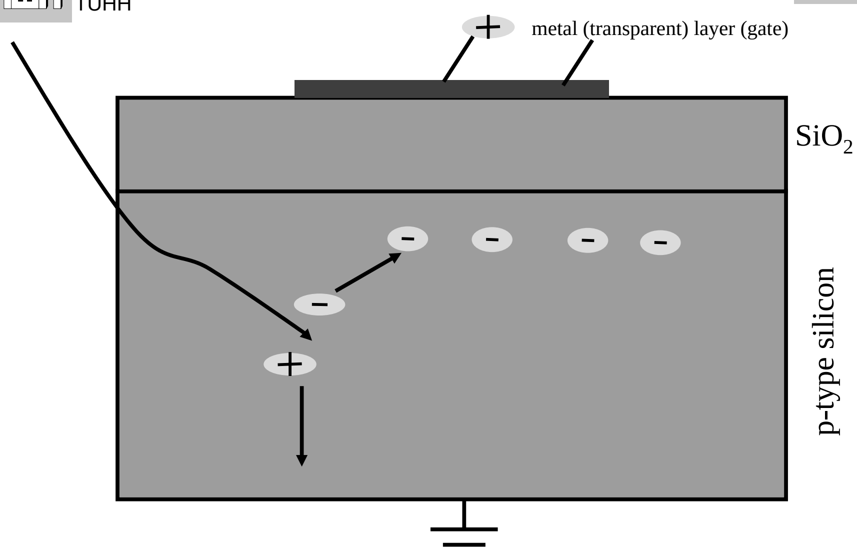
Schematic insertion process



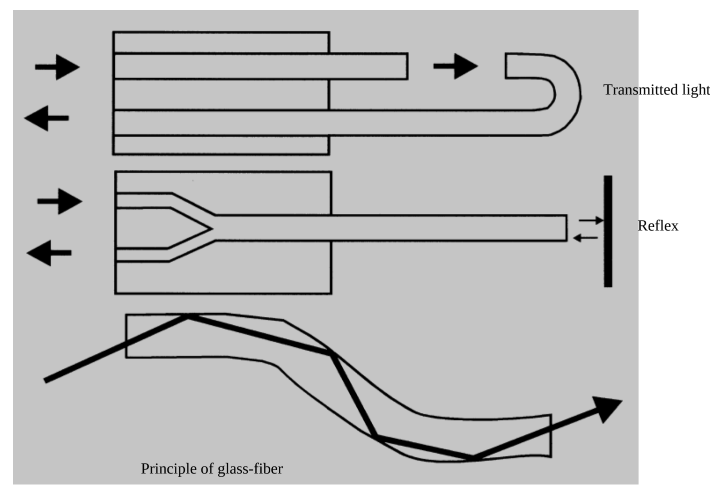
Passive-insertion support



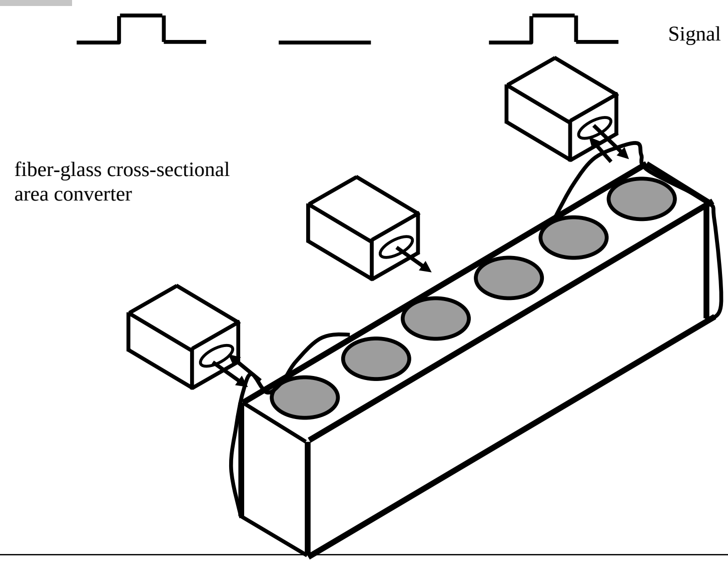
6-Components sensor for robotarms



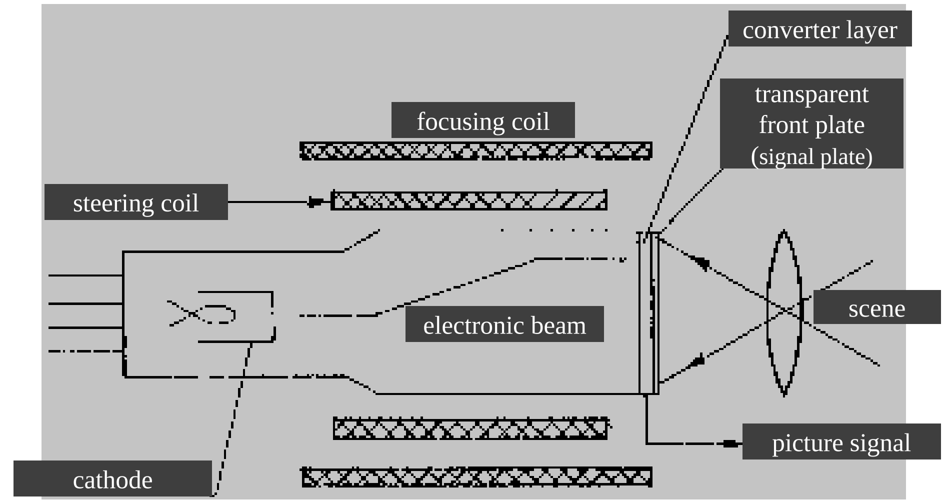
MOS - Condensator



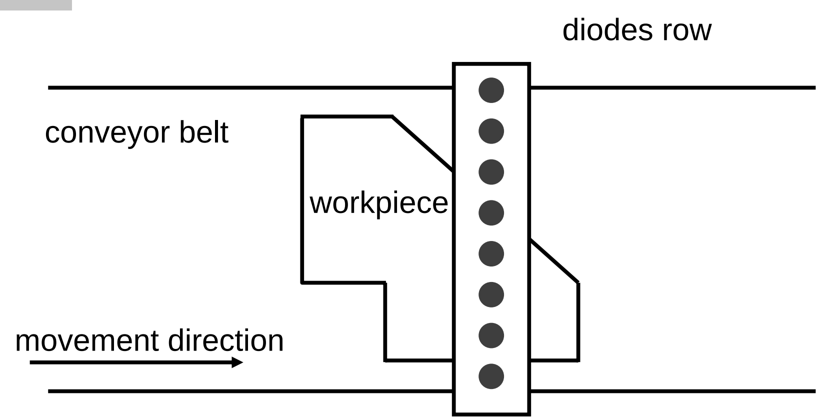
Operating modes of glass-fiber conductors



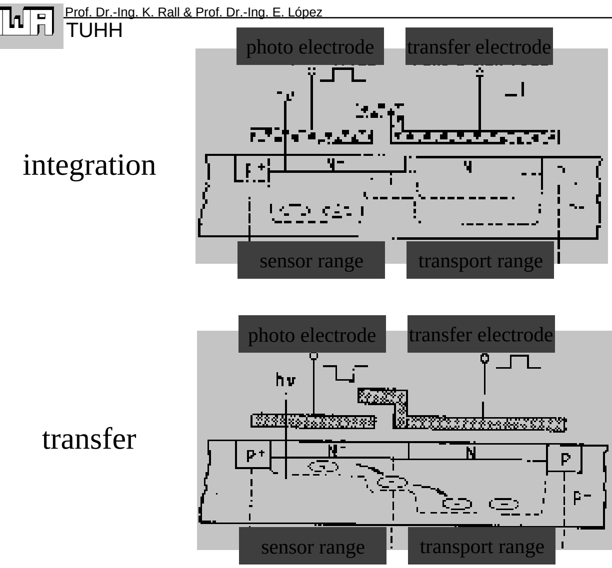
localization of cast burr



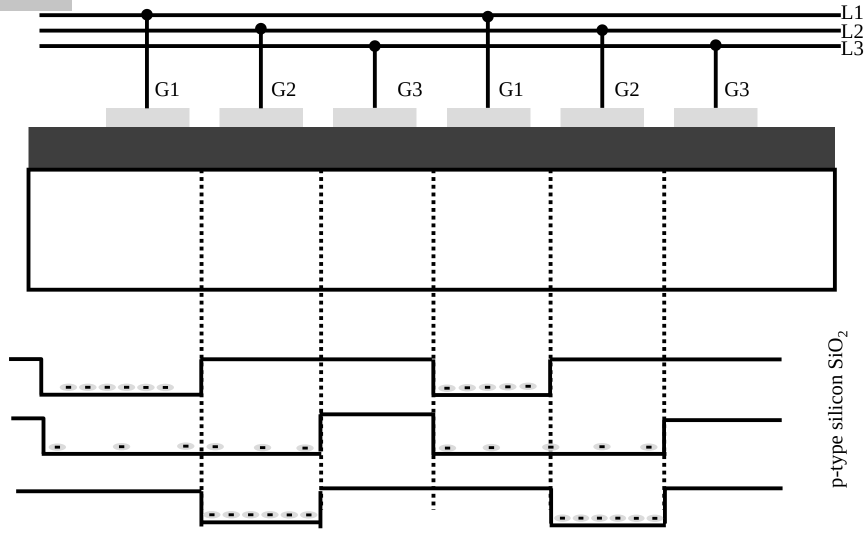
Tube of a TV camera



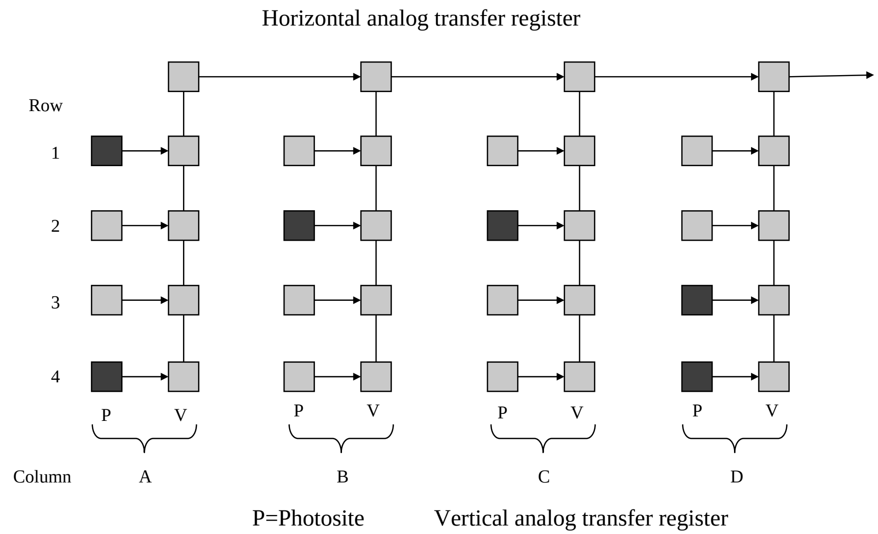
object detection with a semiconductor - diodes row



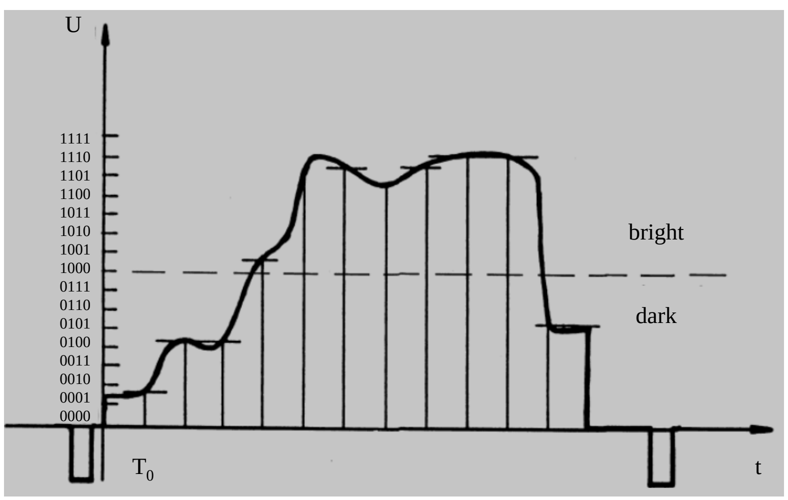
CCD - picture sensor



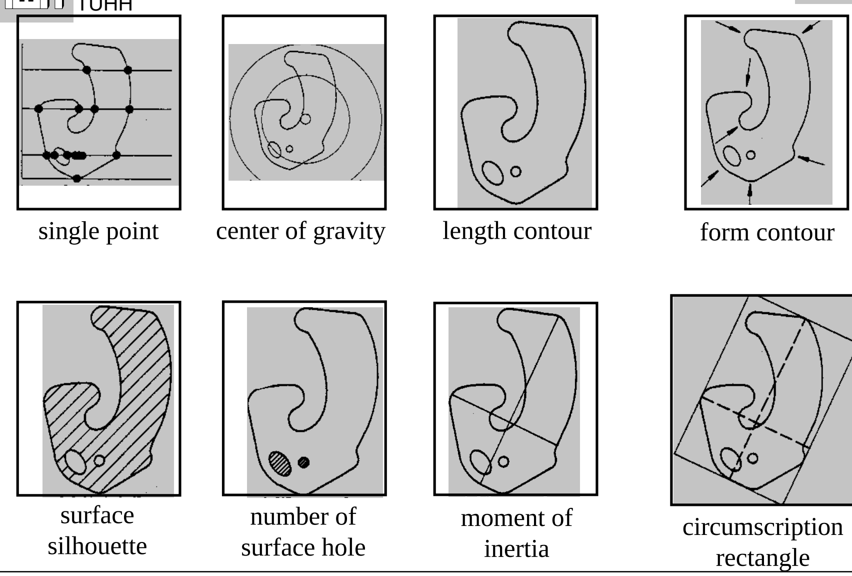
Potential sequence by 3-phase CCD



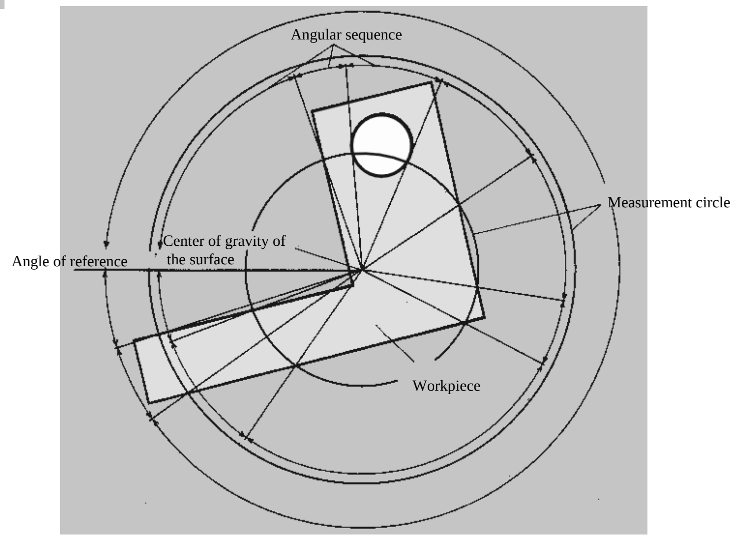
Information processing in CCD



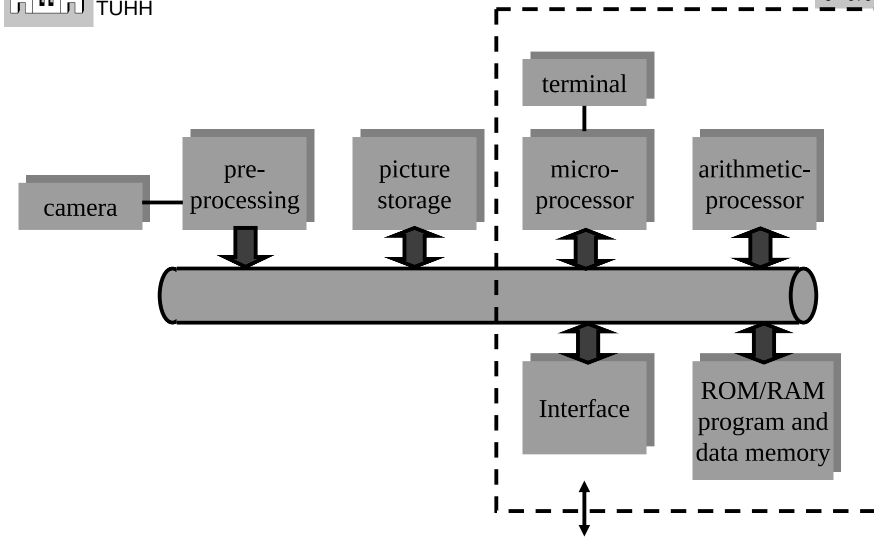
Luminosity (light) signal digitilization of an image line



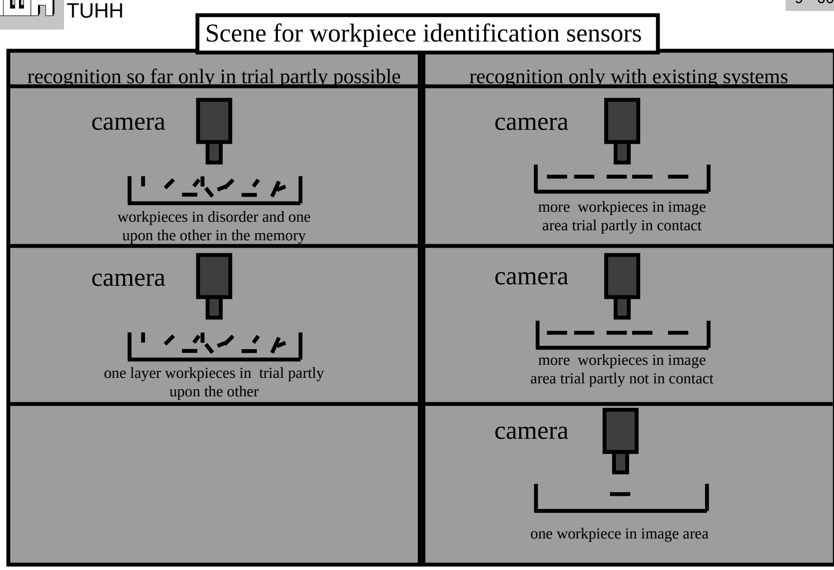
Rotation-independent feature criteria



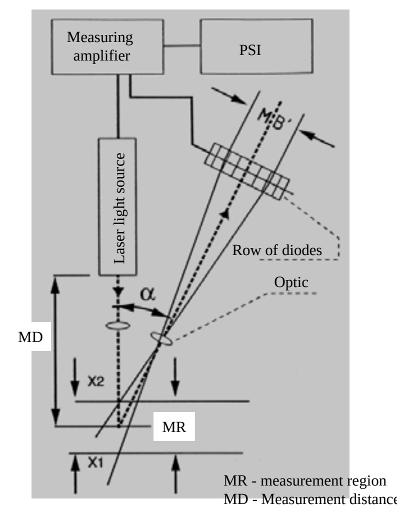
Polar check for workpiece identification



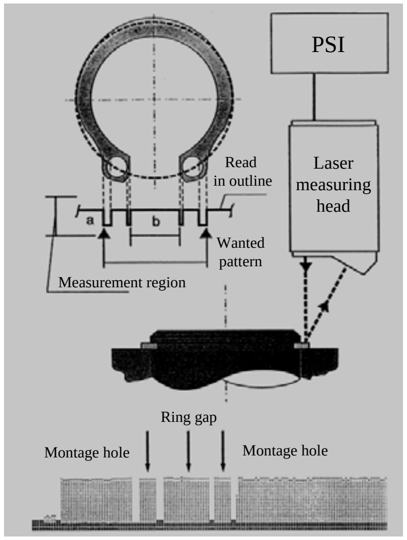
Computer components of an image preprocessing system



optical workpiece identification sensors



Triangulation process



Control of securing with laser scanner