Robotics III: Sensors

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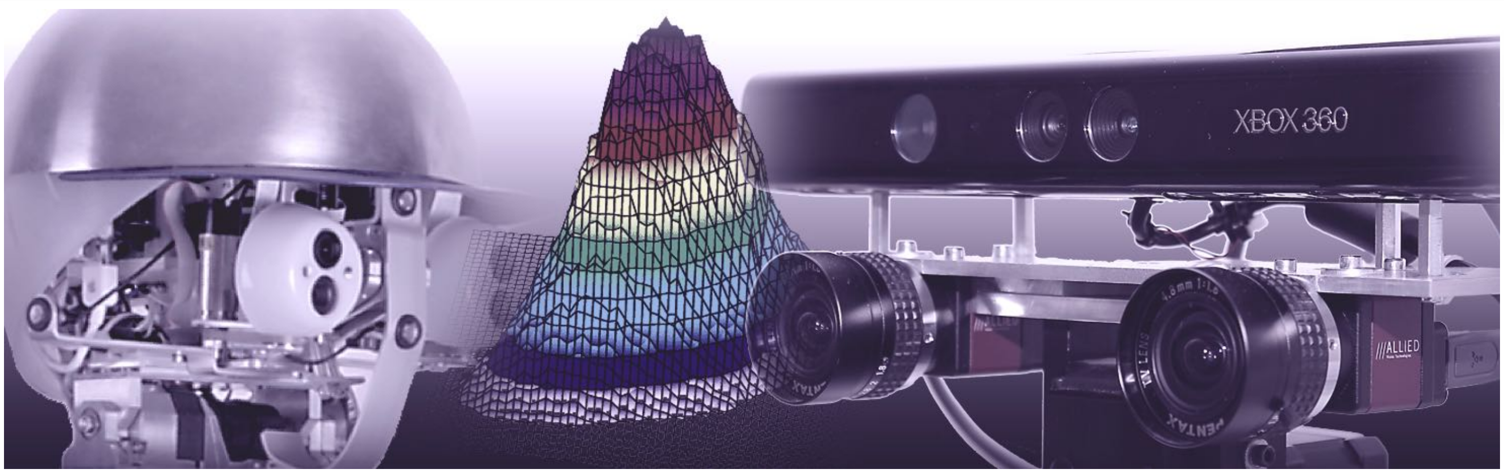


http://www.humanoids.kit.edu

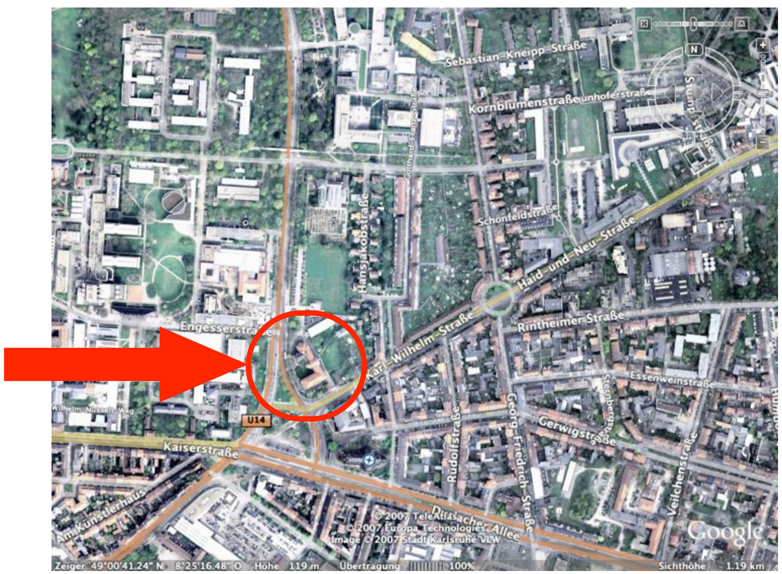
http://h2t.anthropomatik.kit.edu

Institute for Anthropomatics and Robotics

Where can you find us?

HIS – Dillmann, H2T – Asfour are in two places:

- Building 50.20, former Kinderklinik, Adenauerring 2 (Prof. Dillmann, Prof. Asfour, Secretariat),
- Building 50.21, Laboratory building, Adenauerring 4 (next to the Mensa/Uni-Bib, P. Meißner).



Organizational Issues

- Consultation-hour of Prof. Dillmann on Wed. by appointment only.
  - sekrdill@anthropomatik.kit.edu
- Consultation-hour of Prof. Asfour on Wed. from 10 to 12 or by appointment .
  - asfour@kit.edu
- Consultation-hour of Dr. Aksoy by appointment only.
  - eren.aksoy@kit.edu
- Consultation-hour of Mr. Meißner
  by appointment only.
  - pascal.meissner@kit.edu

Organizational Issues

- Actual lecture slides are available on the Web.

- Book (Skriptum): Dillmann „Sensoren in der Robotik“, is also available on the web.
  - Complementary to the lecture slides.

- Web-Server: ilias.studium.kit.edu
  - Lecture slides
  - Book (Skript)
  - Literature

Robotik III

Sensoren in der Robotik

Skriptum zur gleichnamigen Vorlesung

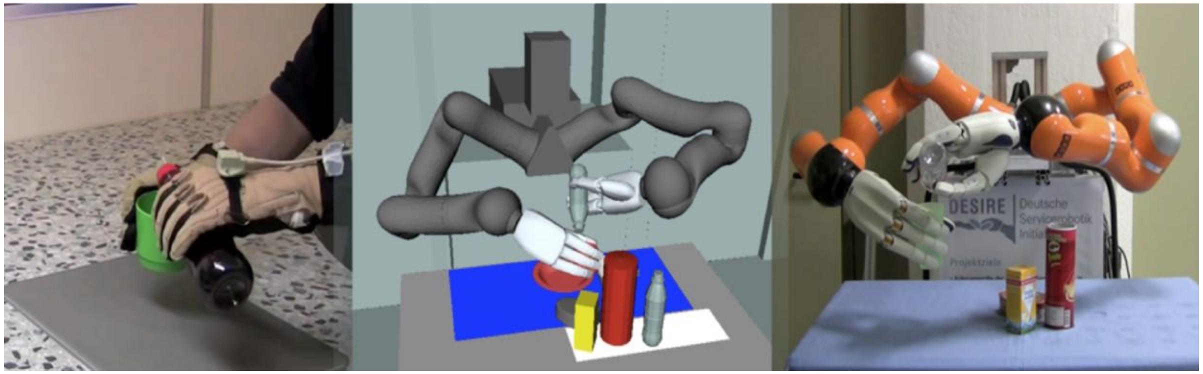
Prof. Dr.-Ing. R. Dillmann
Dipl.-Inform. P. Steinhaus

Universität Karlsruhe (TH)
Fakultät für Informatik
Lehrstuhl Prof. Dr.-Ing. Rüdiger Dillmann

Further Activities

- Robotics II – Humanoid Robotics
- Machine Learning 2 – Advanced Methods
- Biologically Motivated Systems
- Wearable Robotics Technologies

- Bachelor/Master Theses!
- HiWi-Jobs!



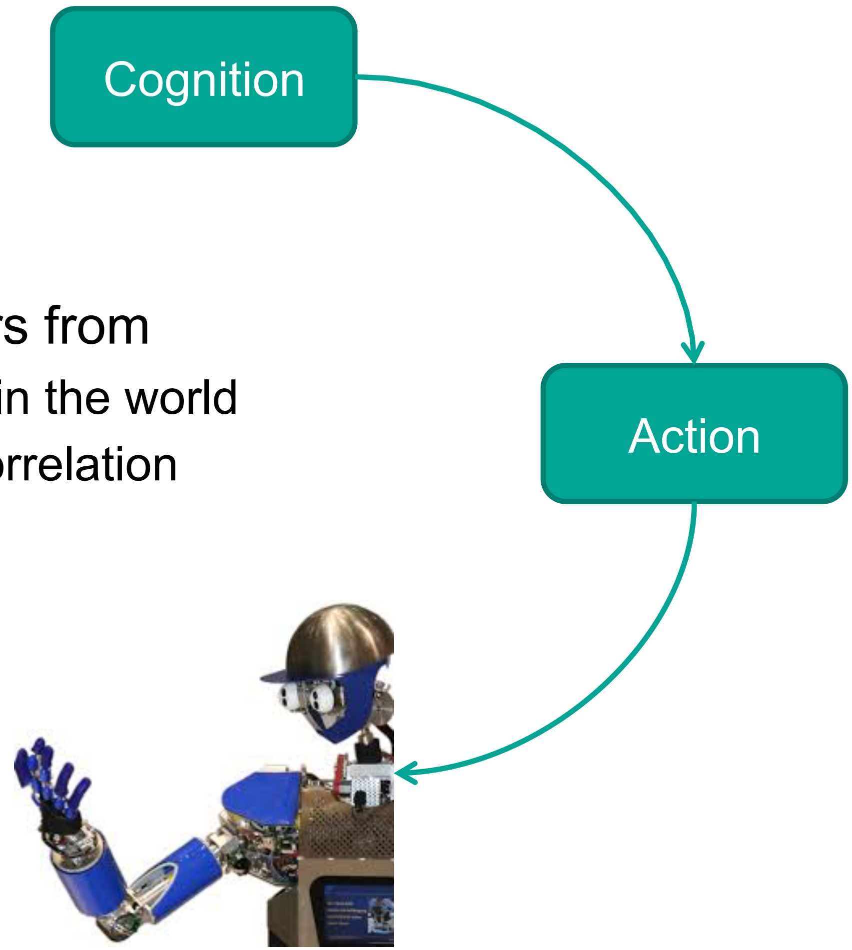
Content of Robotics III

- Introduction to Sensors
- Sensor Technologies (Internal & External Sensor)
- Sensor modeling
- Digital Signal Processing
- Machine Vision
- Environment modeling
- Multi-sensor integration & Fusion
- Applications
- Research activities

- Focus: Visual Perception
  - From data acquisition to environment representation

Open Loop Control

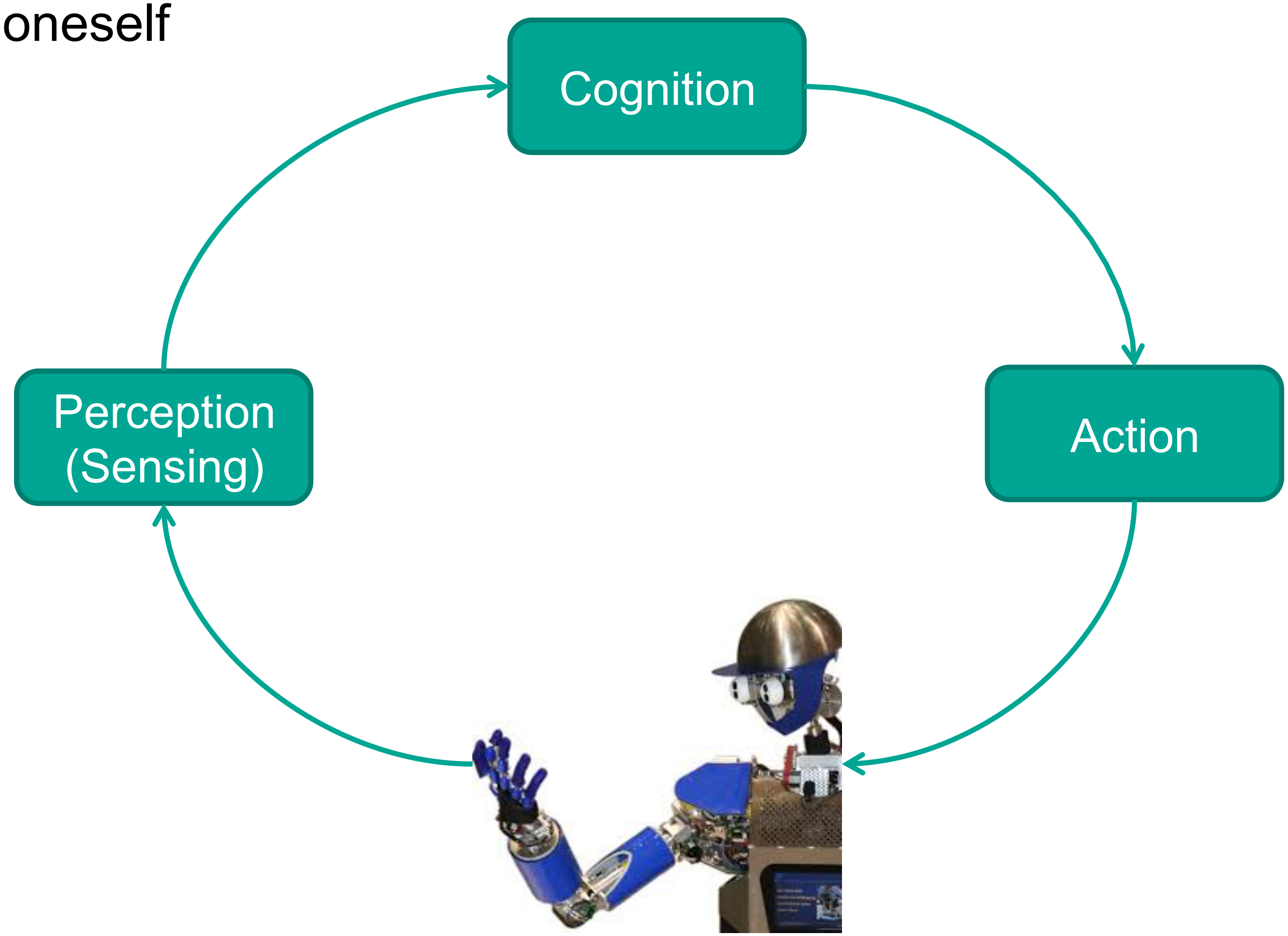
- No sensing input



- Open loop control suffers from
  - Uncertainty, changes in the world
  - Error detection and correlation

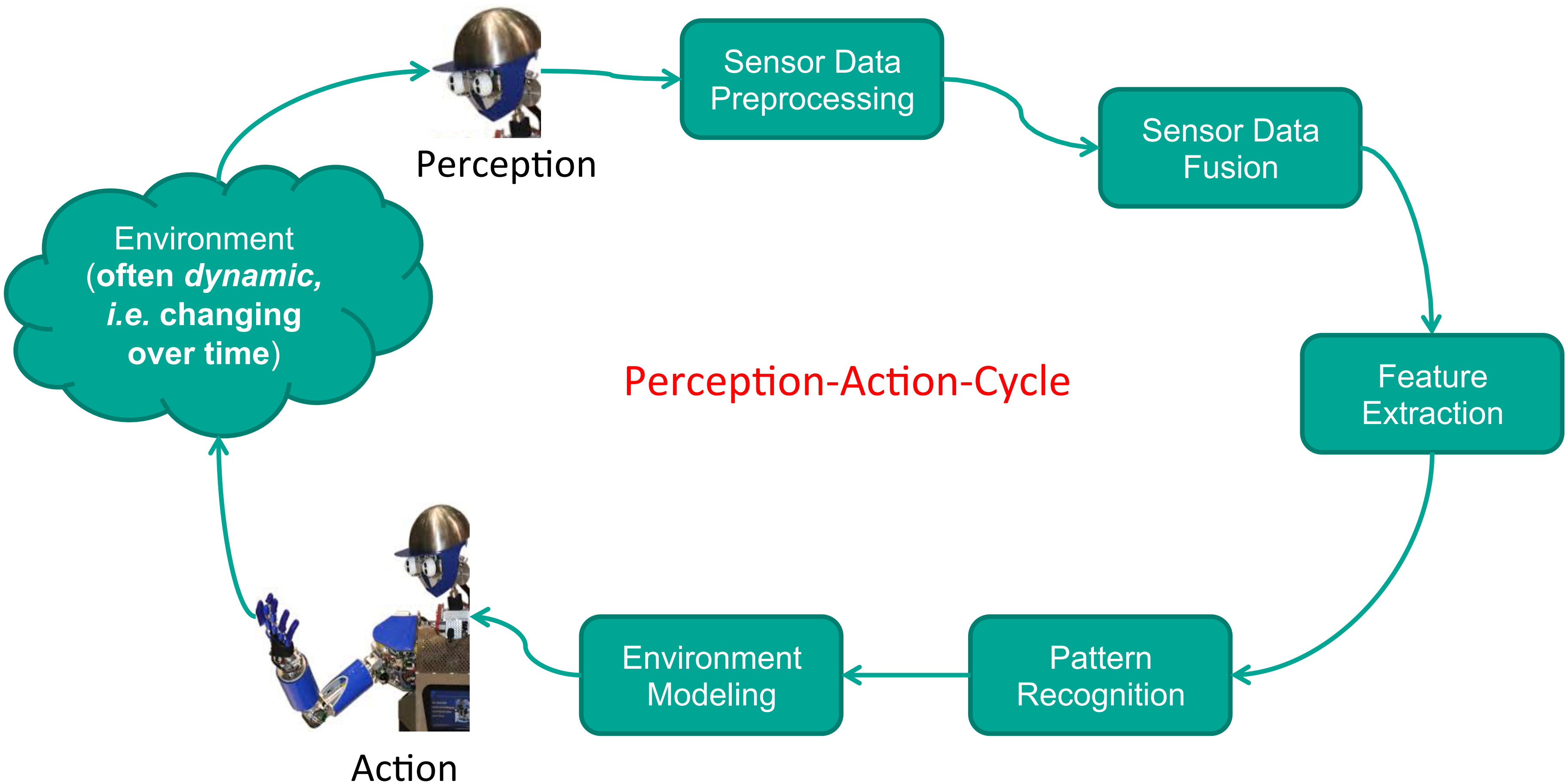
The Sensing Loop

- Feedback control
- Sensors are required to acquire information about the environment and oneself

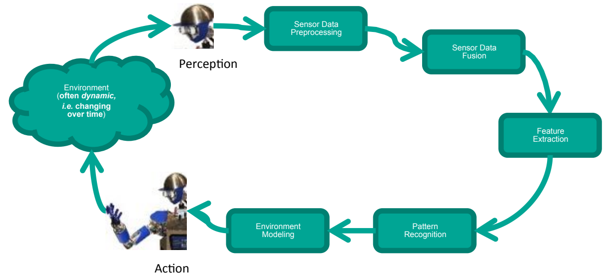


The Sensing Loop

- The Perception-Action-Cycle is crucial to the implementation of interactive, adaptive and situation-based behavior.



The Sensing Loop



- Perception-Action-Cycle
  - **Perception:** Data acquisition, i.e. sampling of analog/digital signals output from various sensor devices
  - **Data Preprocessing:** Filtering, normalization, and/or scaling, etc., of acquired sensory data
  - **Data Fusion:** Combination/fusion of multi-model sensor data leading to robust measurements, reduced uncertainty and increase in information
  - **Feature Extraction:** Exploration of features representing a mathematical model of the sensed environment in order to approximate the natural human perception
  - **Pattern Recognition:** Extracted features are searched for patterns in order to classify the data
  - **Environmental Modeling:** Successfully classified patterns are employed to model the environment of the robotic system
  - **Action:** Execution of the goal oriented tasks, i.e. manipulating the environment using robotic arms, grippers, wheels, etc.

Sensors: Definition

- Sensors are devices that can sense and measure physical properties of the environment
  - For instance, temperature, luminance, weight, distance, etc.

- Sensors deliver *low-level* information about the surrounding environment of the robot. This information is also
  - limited
  - inaccurate
  - noisy (imprecise)

- Therefore, sensors return an incomplete description of the world

Sensors: Definition

- Sensors are physical devices that receive a signal or stimulus and reacts to it with an electrical signal

- Any sensor is an energy converter. No matter what you try to measure, you always deal with energy transfer from the object of measurement to the sensor.

- Sensors range from simple to complex in the amount of information they provide. For instance,
  - A switch is a simple on/off sensor
  - A human retina is complex sensor consisting of more than a hundred million photosensitive elements (rods and cones)

Sensors: Definition

- Sensors constitute the perceptual system of a robot

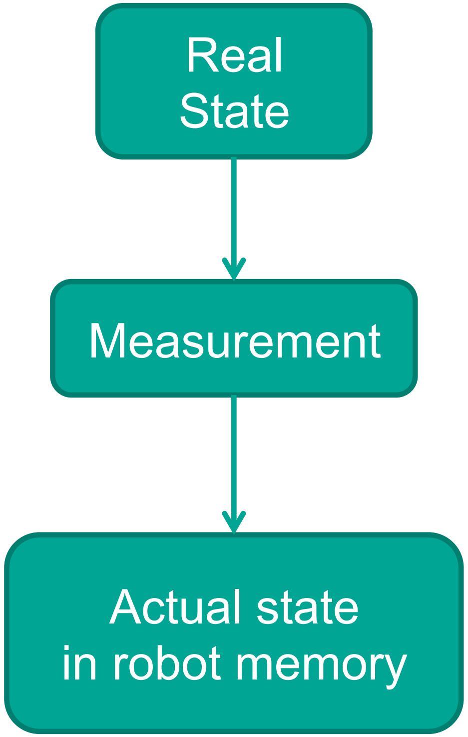
- Sensors allow to close the feedback control loops that secure efficient and autonomous operation of robots in real-life applications

- A robot’s intelligence depends on
  - the quality and quantity of its sensors.
  - the ability to process and speed of processing sensory input

- Types of senses are called sensory modalities (e.g. multi-modal sensory data!)

Sensors: Definition

- Sensors are devices that measure the attributes of the world.
- Sensors do not provide state/symbols, but rather data, i.e. signals, or physical quantities!
- We have to convert the signal from a sensor into useful state for the robot
- Therefore, we need to process the signal, for instance, by means of feature extraction, pattern recognition, etc.



Sensor Types – In Humans

- Sense:
  - Vision
  - Audition
  - Gustation
  - Olfaction
  - Tactition

- Sensor:
  - Eyes
  - Ears
  - Tongue
  - Nose
  - Skin



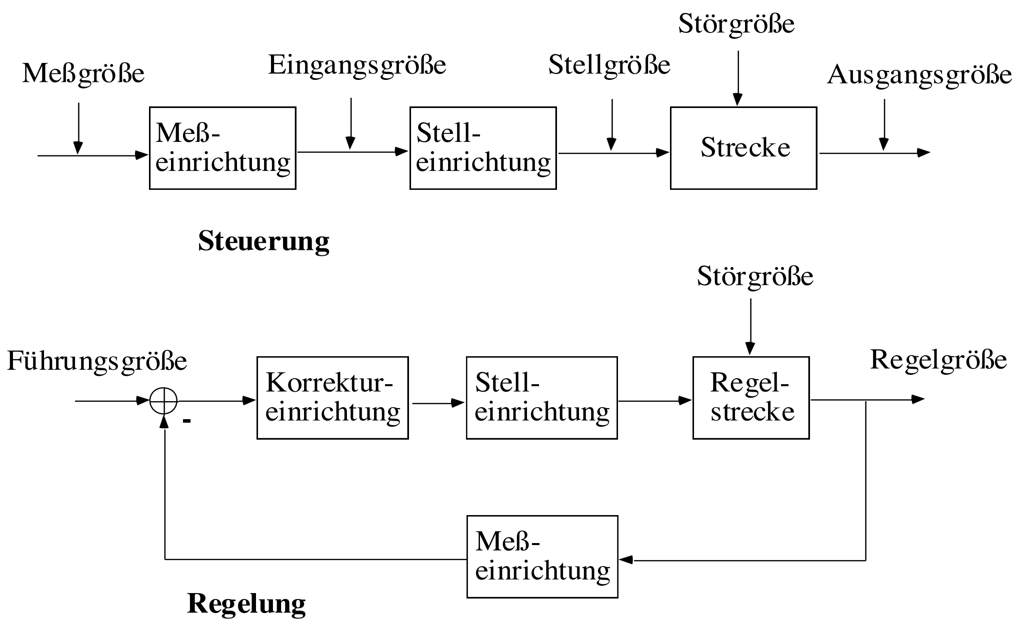


Introduction to Sensors: Definition

- *Sensor*:
  (lat.: Sensus = „capable of sensitivity“)

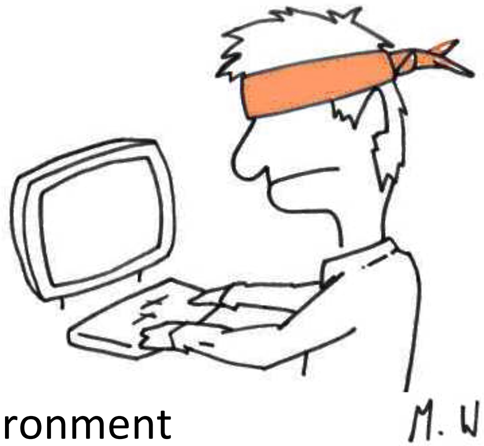
- Definition: System that converts a physical quantity and its change to appropriate (in our case electrical) signals

Use in systems where the time profile of the disturbance variable is unknown (regulation)



Problems – Sensors for Robots

- **Task:**
  - Capture the environment
    in non-defined surroundings.



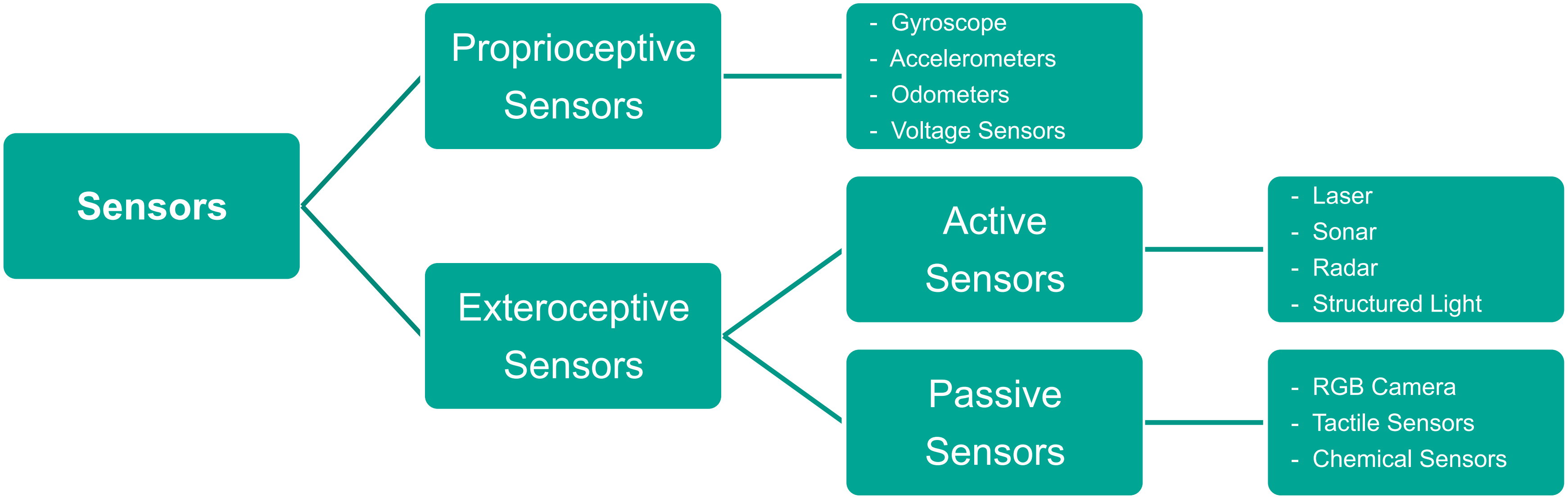
- **Goal:**
  - Sensors provide only partial information about the environment
    - ➔ Choice of „suitable“ sensors.
  - Modeling the sensor characteristics
    - ➔ Determine the relationship between the real world & the measurement results.
  - Digital evaluation of sensory measurements
    - ➔ Basics of digital signal processing and machine vision.
  - Use of multiple sensor types and in multi-sensor systems
    - ➔ Fusion of measured values.

Sensor Types – In Robots

- In general, robotic sensors are distinguished into two groups:
  - **Analog sensors:** provide analog output signals which need analog-to-digital (A/D) conversion. E.g. analog infrared distance sensor, microphone, and analog compass.
  - **Digital sensors:** are more accurate than analog sensors, and their outputs may be of different form. E.g. they may have a “synchronous serial” form (i.e., bit by bit data reading), or a “parallel form” (e.g., 8 or 16 digital output lines).
- Sensors are also classified as:
  - **Active sensors:** emit some form of energy into the environment and then measures the return to understand the environment (e.g., infrared sensor, laser range finders.).
    - More robust, less efficient
  - **Passive sensors:** monitor the environment without affecting it, or in other words receive energy already in the environment (e.g., gyroscope, vision camera)
    - Less intrusive, but depends on environment, e.g. temperature probes, cameras.

Sensor Types – In Robots

- Sensors are also classified as:
  - **Internal (proprioceptive) sensors:** monitor the robot internal state.
    - Internal sensors include the sensors that measure motor speed, wheel load, robot arm joint angles, and battery voltage.
  - **External (exteroceptive) sensors:** monitor the robots environment.
    - External sensors include sensors that measure distance, sound amplitude, and light intensity.
- Proprioceptive and exteroceptive sensors combine to make the robot's perceptual system



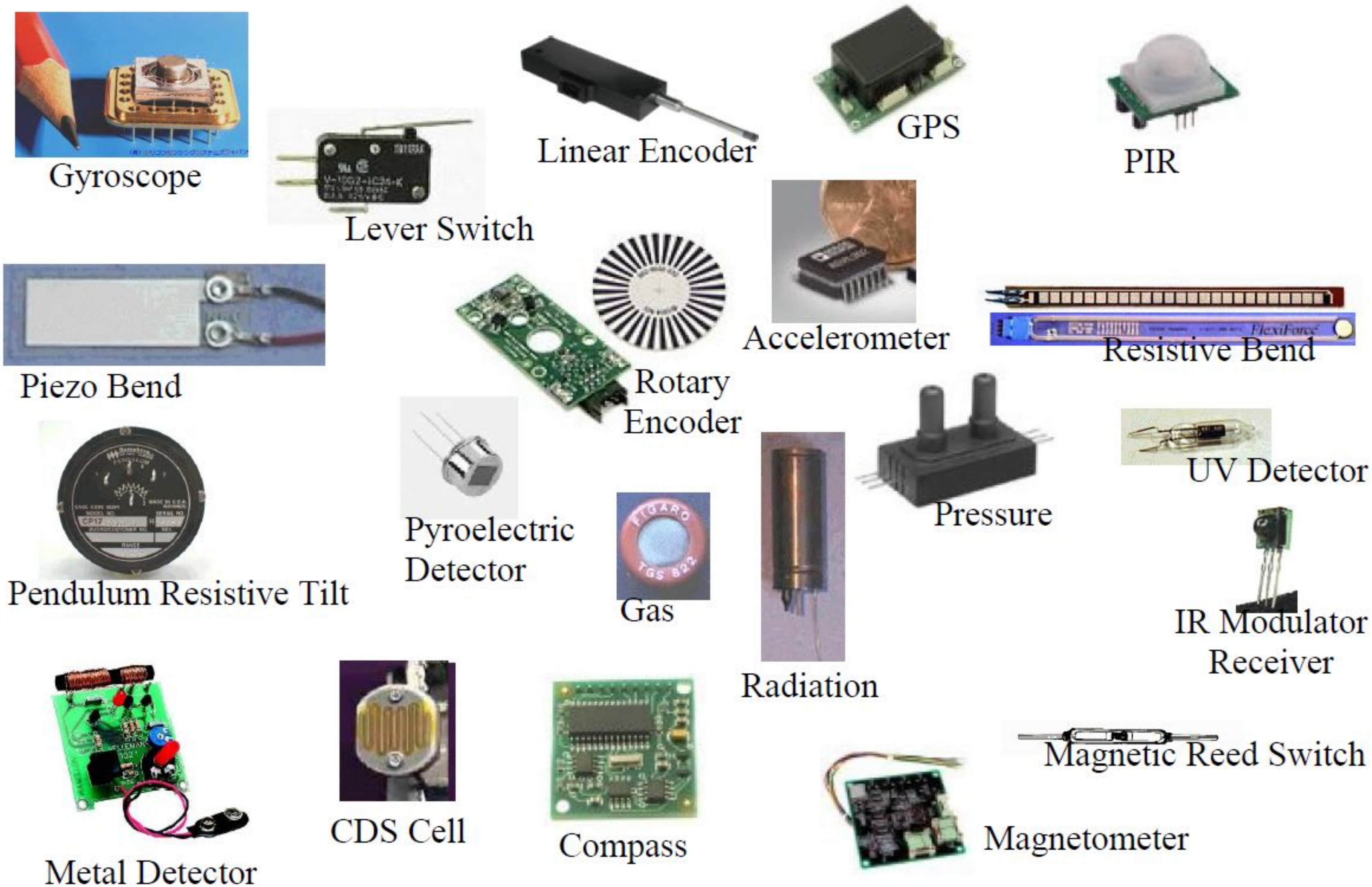
Sensor Types – In Robots

- The sensory systems for robots can also be categorized as follows:
  - **Mechanical Systems:** require a physical contact between the robot and the sensor. Frequently, they are integrated in the robot body.
  - **Acoustic Systems:** employ ultrasound frequencies and use the directionality and the time-of-flight measurement of sent and received signals, for instance, to compute object position.
  - **Electromagnetic Systems:** also use the directionality and the time-of-flight measurement like in acoustic systems. In both cases, a free “line of sight” between the transmitter and the receiver is required.
  - **Magnetic Systems:** employ the spatial configuration of static magnetic fields of the Earth and solenoids for the calculation of the position.
  - **Optical Systems:** use appropriate vision cameras (monocular, binocular, omnidirectional).

Sensor Characteristics

- Sensors are characterized by various properties that describe their performances
  - **Sensitivity:** the degree to which the changes of the input signal affect the output signal
  - **Linearity:** Constancy of output/input. In a more general formulation, linearity implies that $f(ax+by) = af(x)+bf(y)$, where a and b are constant parameters.
  - **Dynamic range:** The spread between the lower and upper limits of input values for which the sensor is working normally
  - **Response time:** Time required for a change in input to cause a change in the output
  - **Accuracy:** Difference between the measured and actual (ground truth) values
  - **Repeatability:** Difference between repeated measures
  - **Resolution:** The minimum difference of the measured variable that can be recognized by the sensor, i.e. smallest observable increment
  - **Bandwidth:** The maximum rate or frequency of readings (measurements) the sensor can provide. The number of readings per second provides the sensor's frequency measured in hertz.

Popular Sensors in Robotics



Sensor types

- Mechanic Sensors (e.g. force sensors)
- Temperatur Sensors
- Chemical Sensors (e.g. H^+-Ion Sensor)
- Biosensors (e.g.Glucose Sensor)
- Optical Sensors
- Acoustic Sensors
- Magnetic Sensors
- Gas Sensors (e.g. Oxygen sensor)
- …

Sensor: Structure

Elementary Sensors

(Recording of a measured value and image signal)

E.g.: Photodiode, CCD

Integrated Sensors

(Additional signal processing: amplification, filtering, linearization, normalization)

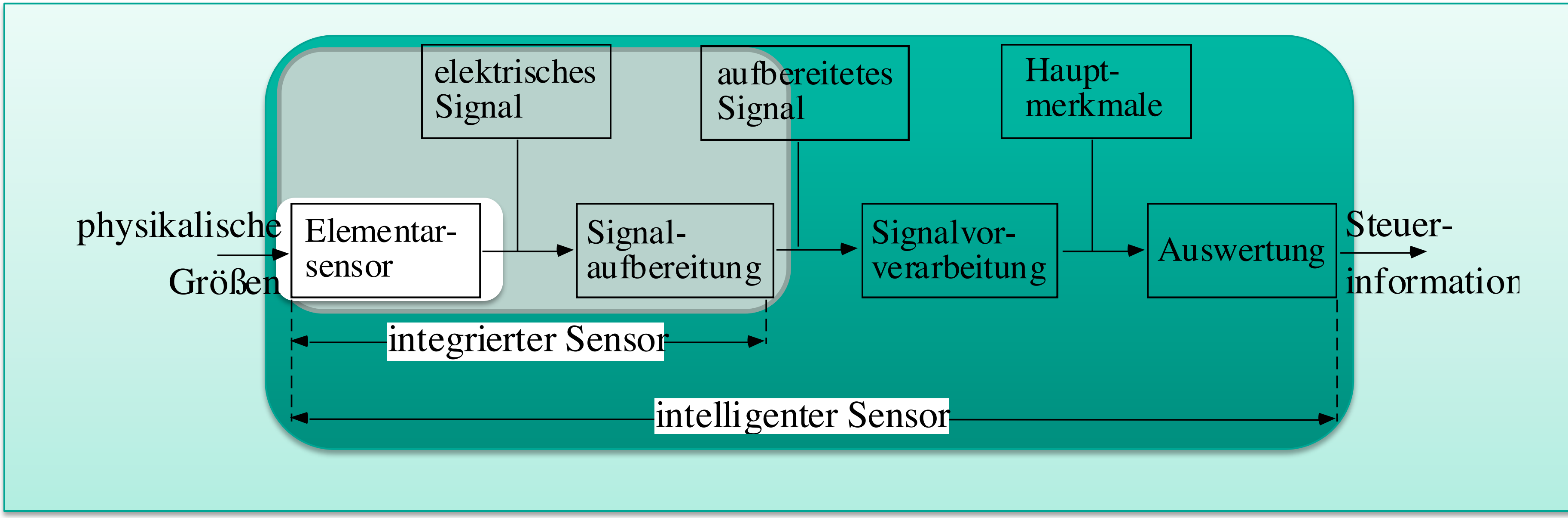
E.g.: CMOS

Intelligent Sensors

(Integrated sensor with computer-controlled evaluation. Output: processed data)

E.g.: Digital camera with face-recognition

Information flow in a Sensor



Example: Ultrasonic distance sensor

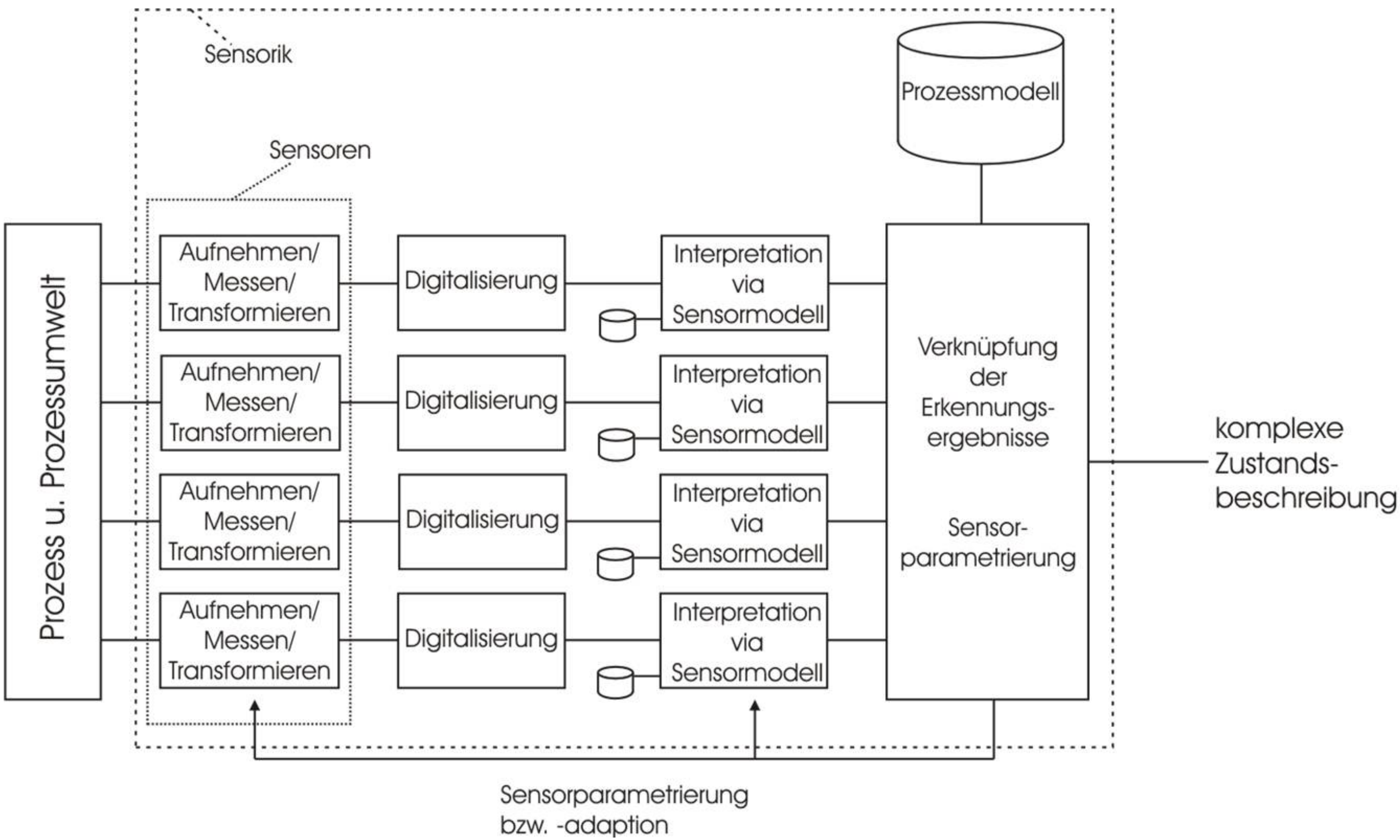
Piezo crystal in the microphone

Output of the runtime measurement

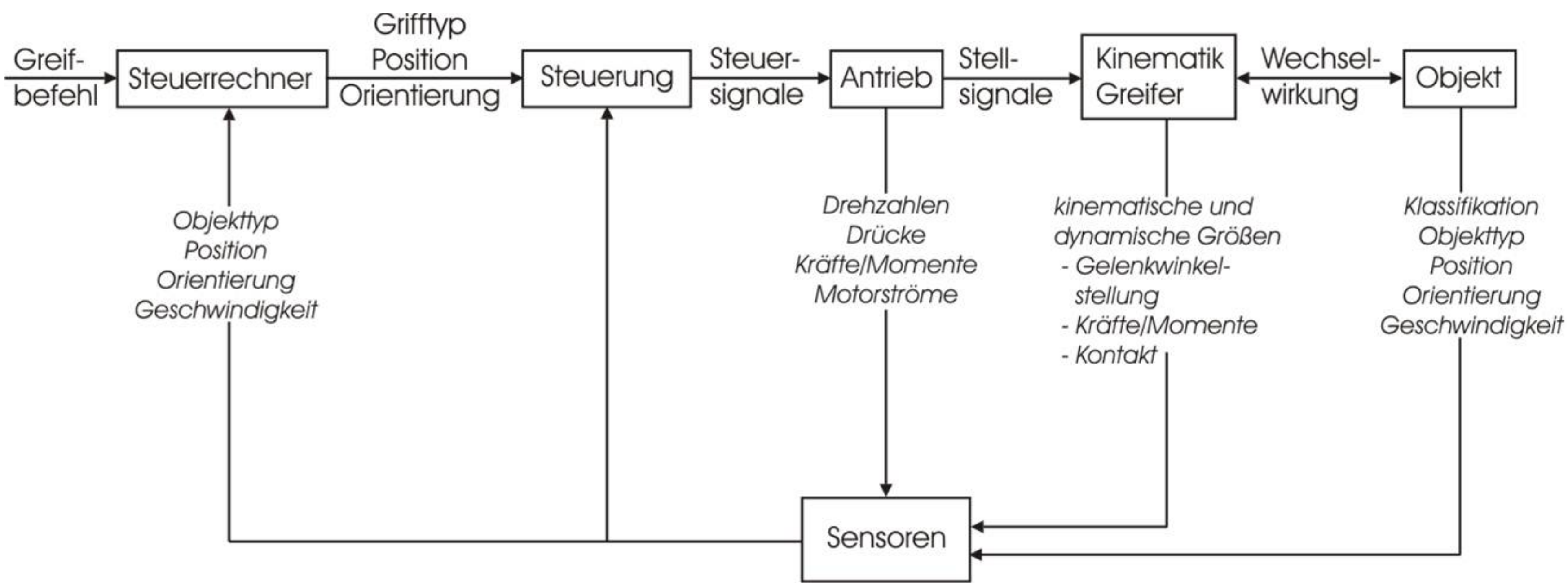
With 89% Probability the object is in 3,2m

Usually, this model of the single-stage sensor feedback or signal interpretation is not sufficient.

Schema of a Recognition System



Sensor Application



Sensor Types

Classification of sensors according to their functions:

Sensors in Robotics

Internal (Proprioceptive) Sensors:

Monitor the robot internal state

E.g.: Velocity sensors, position sensors.

External (Exteroceptive) Sensors:

Monitor the robots environment

E.g.: Tactile sensors, Distance sensors.

Sensor Types – Internal (Proprioceptive) Sensors

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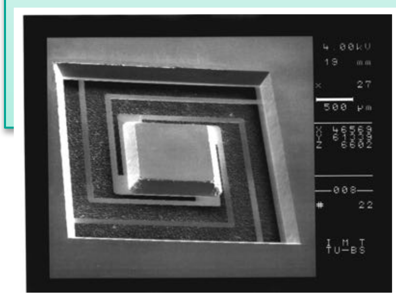
Internal Sensors

Position Sensor	Velocity Sensor	Acceleration Sensor	INS (Inertial Navigation System)
Potentiometer Optical Encoders	Tachogenerator Optical Encoders	Piezoresistive Piezoelectric	Micro-mechanical Vibrating gyroscope



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Sensor Types – External (Exteroceptive) Sensors

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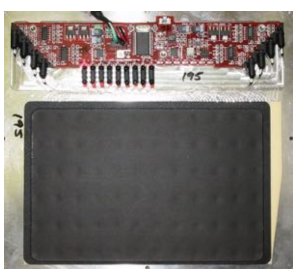
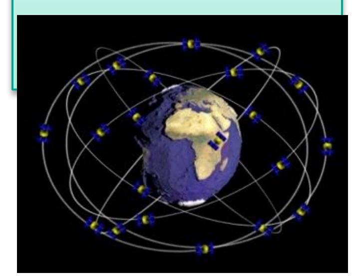
External Sensors

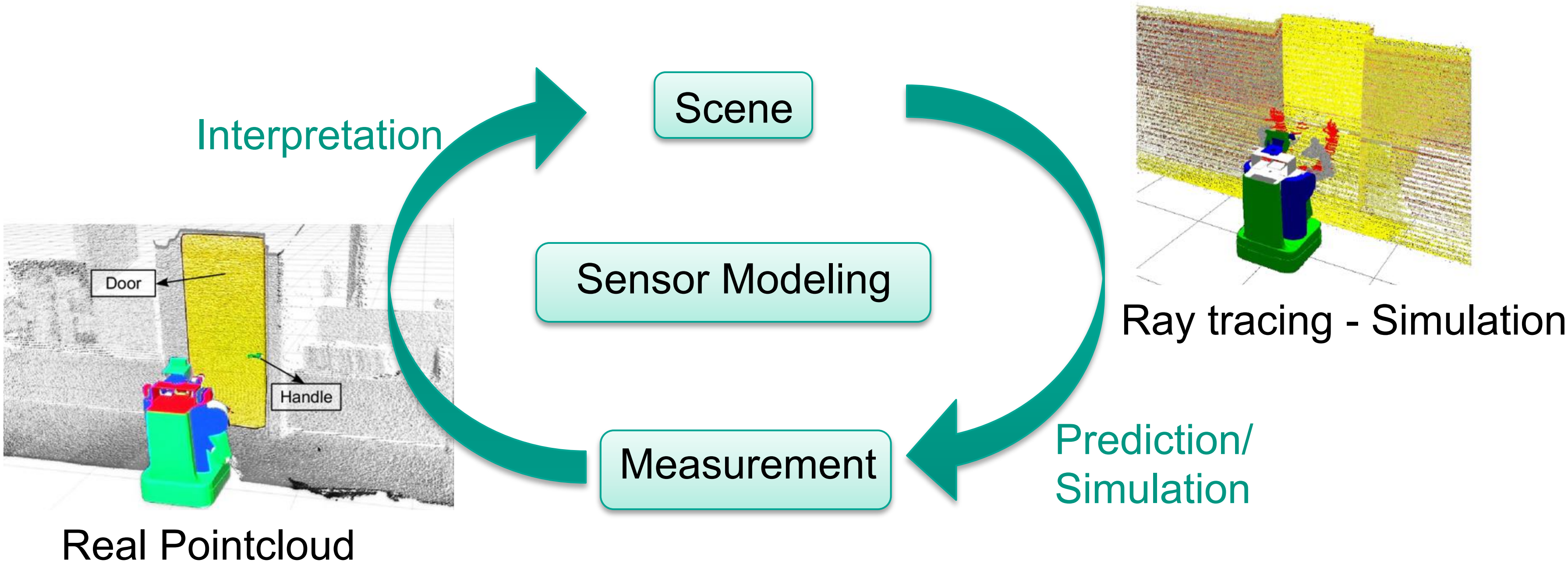
- **Tactile Sensors**
  - Touch & Slip Sensors
  - Force/Torque Sensors
- **Proximity Sensors**
  - Capacitive Sensors
  - Optical Sensors
  - Acoustic Sensors
- **Distance Sensors**
  - Runtime-based
  - Triangulation-based
- **Visual Sensors**
  - Photodiodes
  - CCD/CMOS
  - Stereo
- **Position Sensors**
  - GPS
  - Natural/ artificial Landmarks





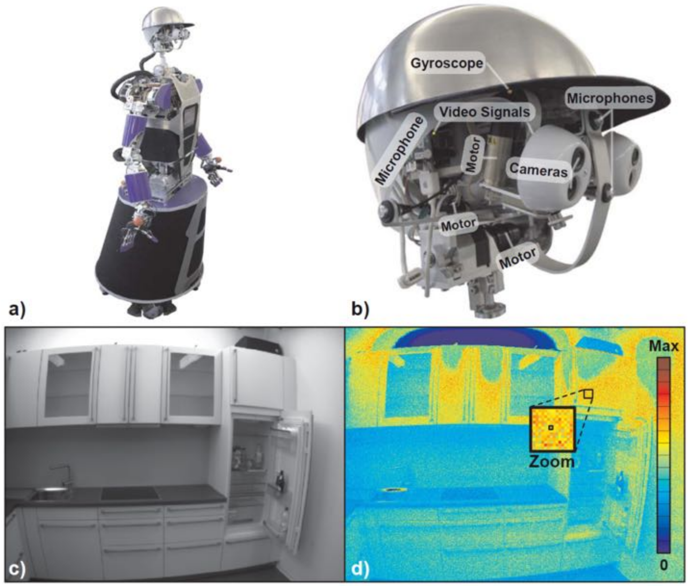
Sensor Modeling

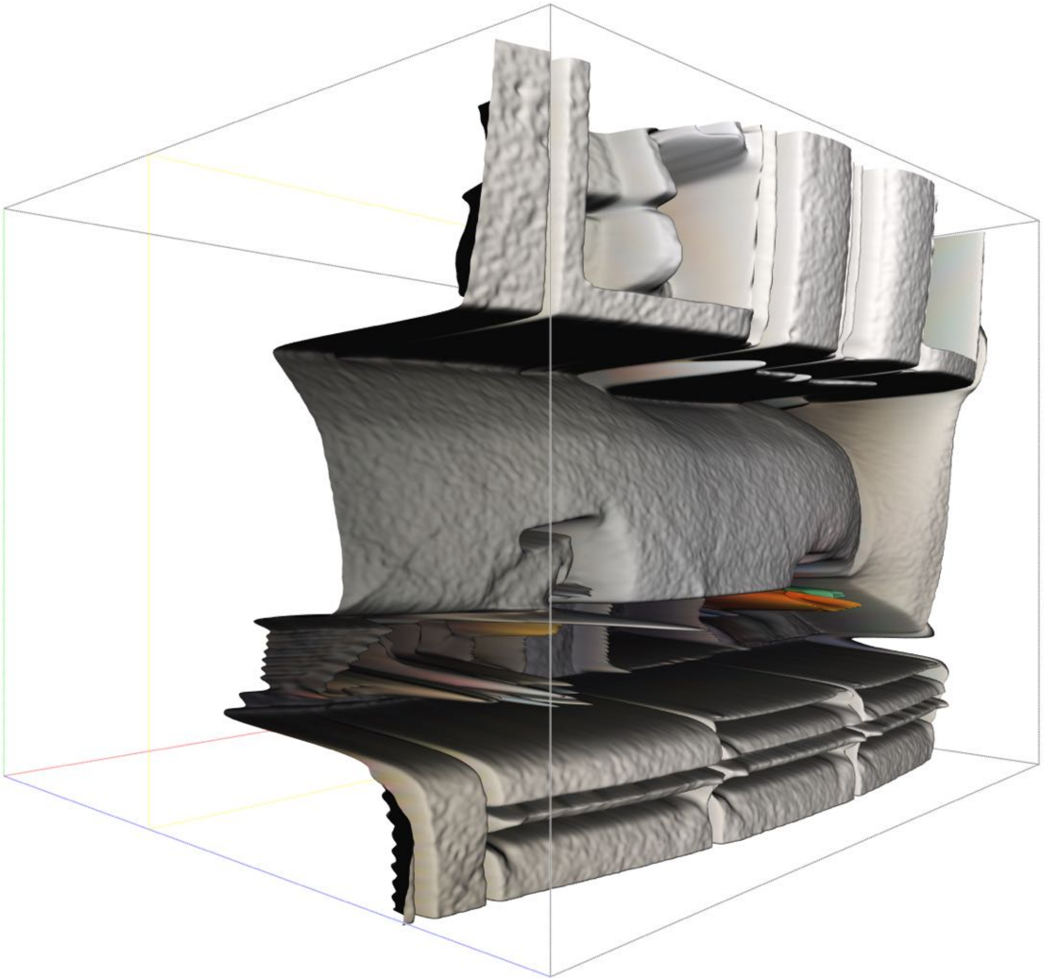
- Relation between the real world and measurement results
- Sensor model: mathematical description of the sensory data characteristics



Sensor Modelling –
Calibration of Visual Sensors for Humanoid Robots

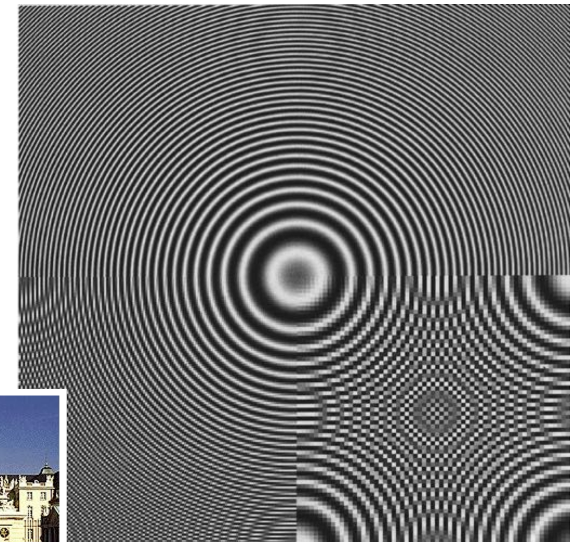
- Robust Image Acquitions
- Camera Focussing
- Camera Color Adjustment
- High Contrast Images(HDR)

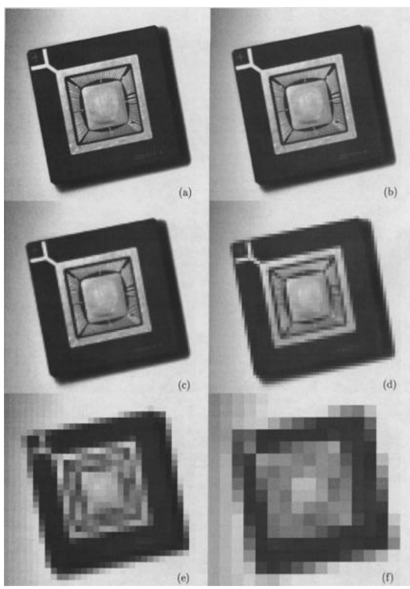


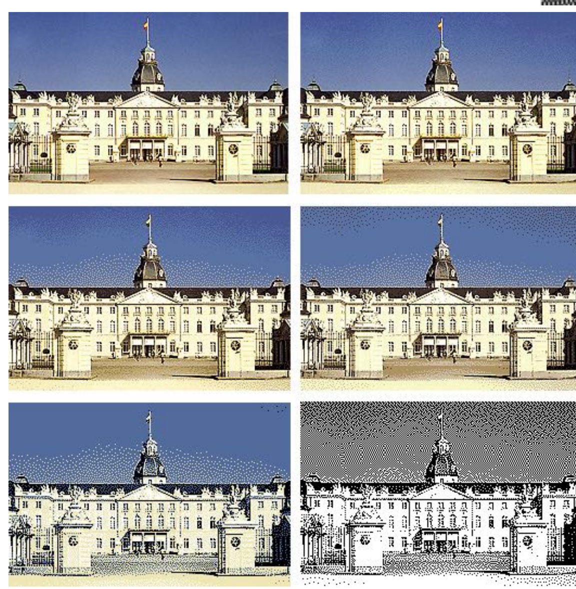


Digital Signal Processing

- Sampling
- Quantization
- Fourier - Transformation
- Sampling Theorem

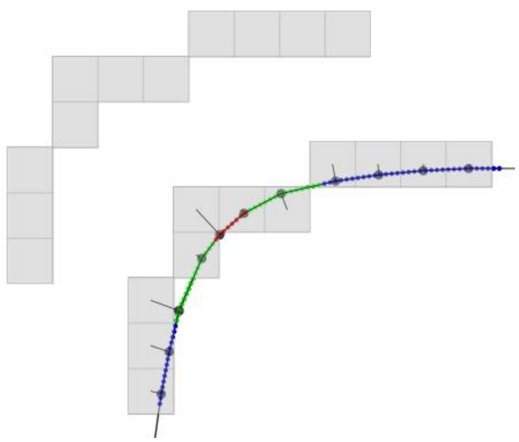


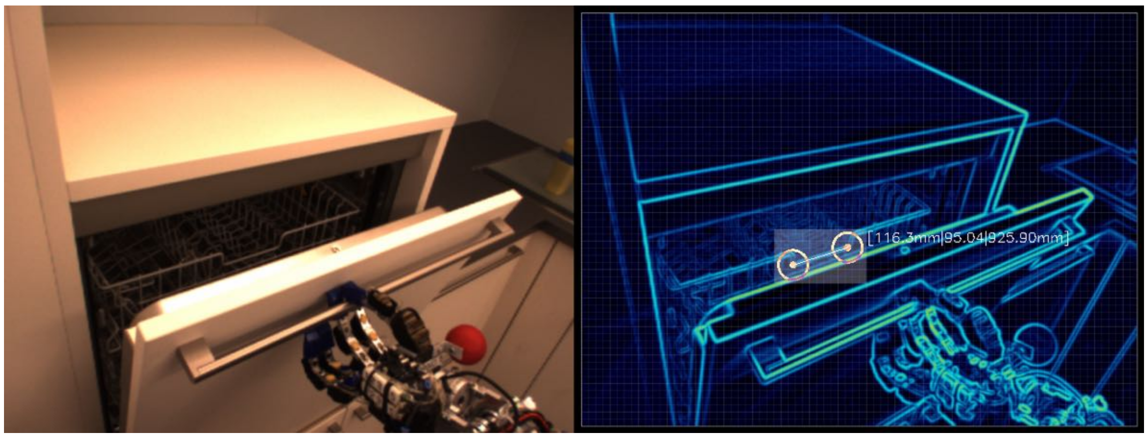




Machine Vision: Basic Image Processing

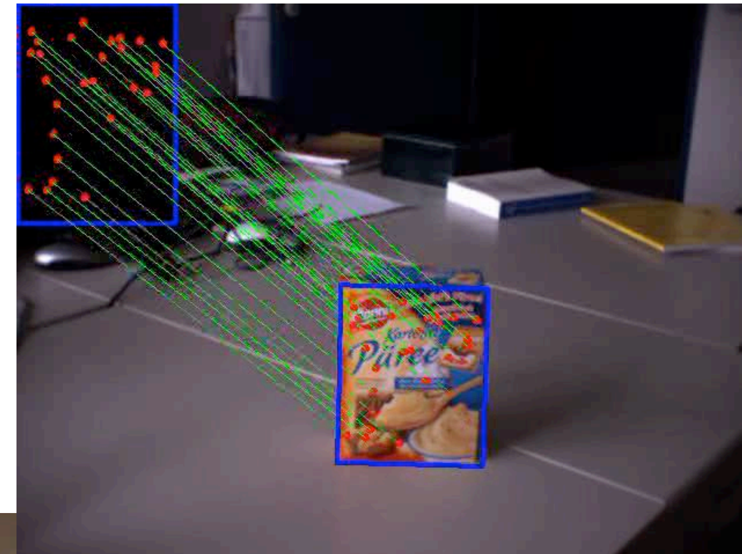
- Color Segmentation
- Subpixel Accurate Edge Detection
- (Generalized) Hough – Transformation





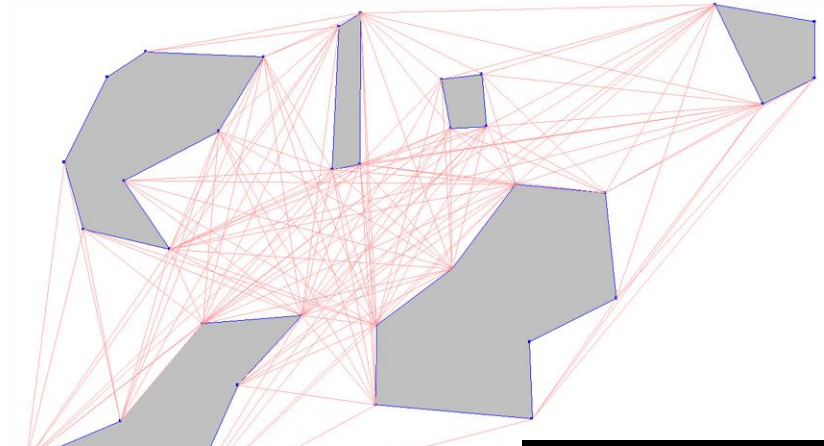
Machine Vision: Object Recognition and Localization based on Point Features

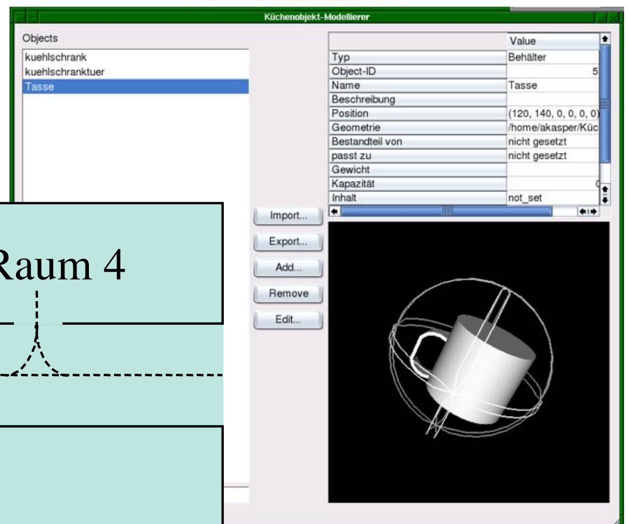
- Feature Detectors
- Descriptors
- Example: SIFT, SURF, MSER
- Matching, Verification, Localization

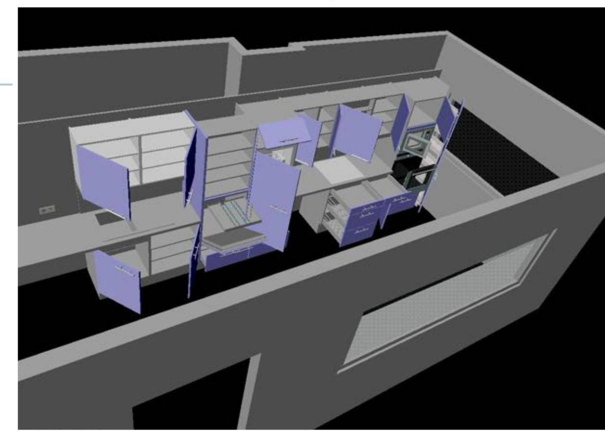


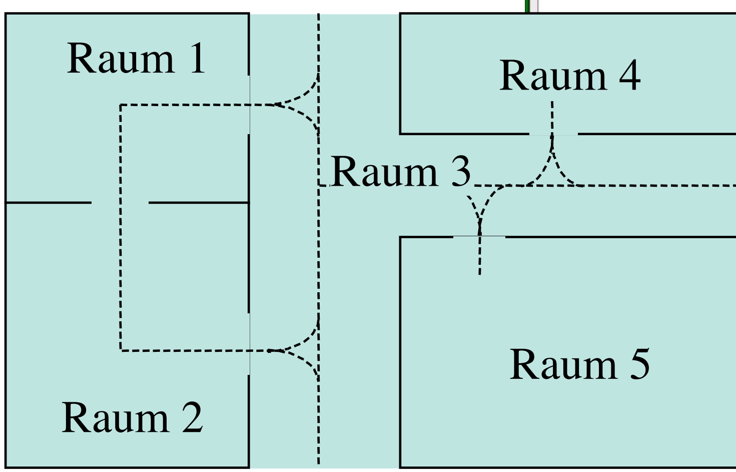
Scene (Environmental) Modeling

- Geometric Models
- Topological Models
- Semantic Models



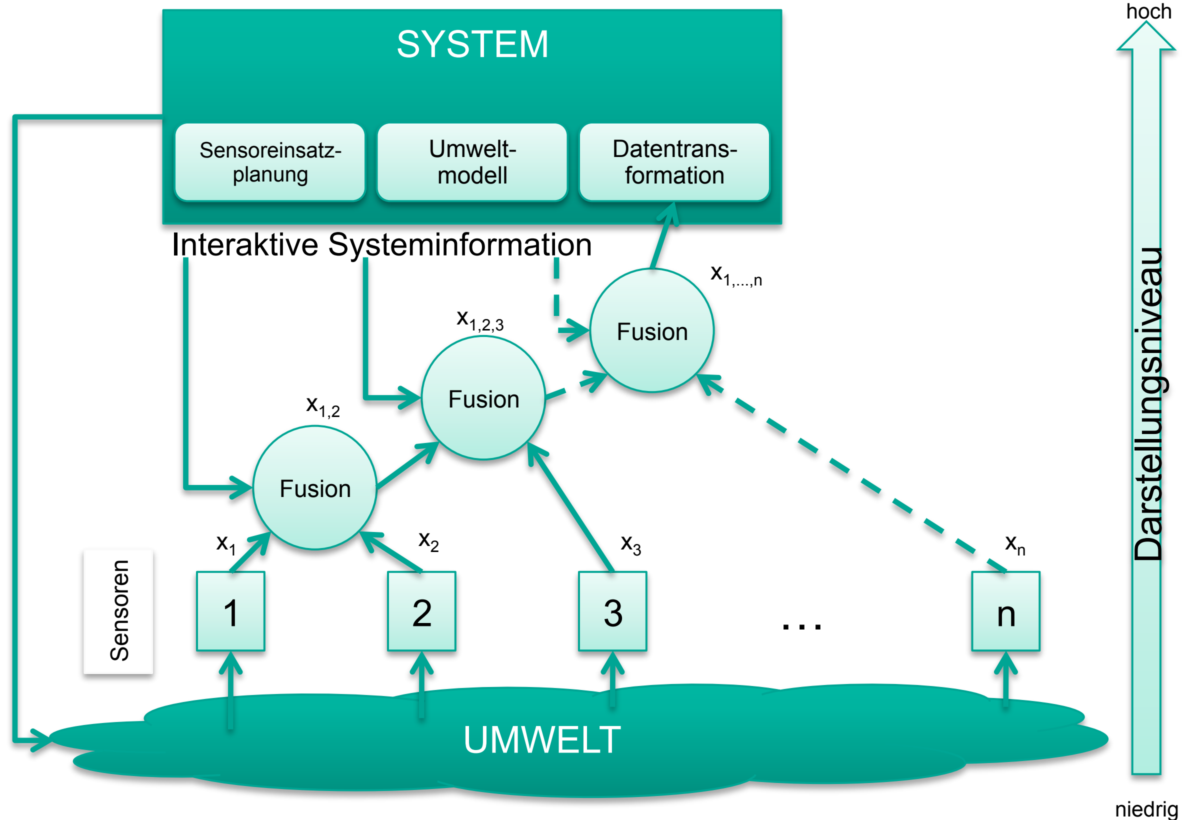


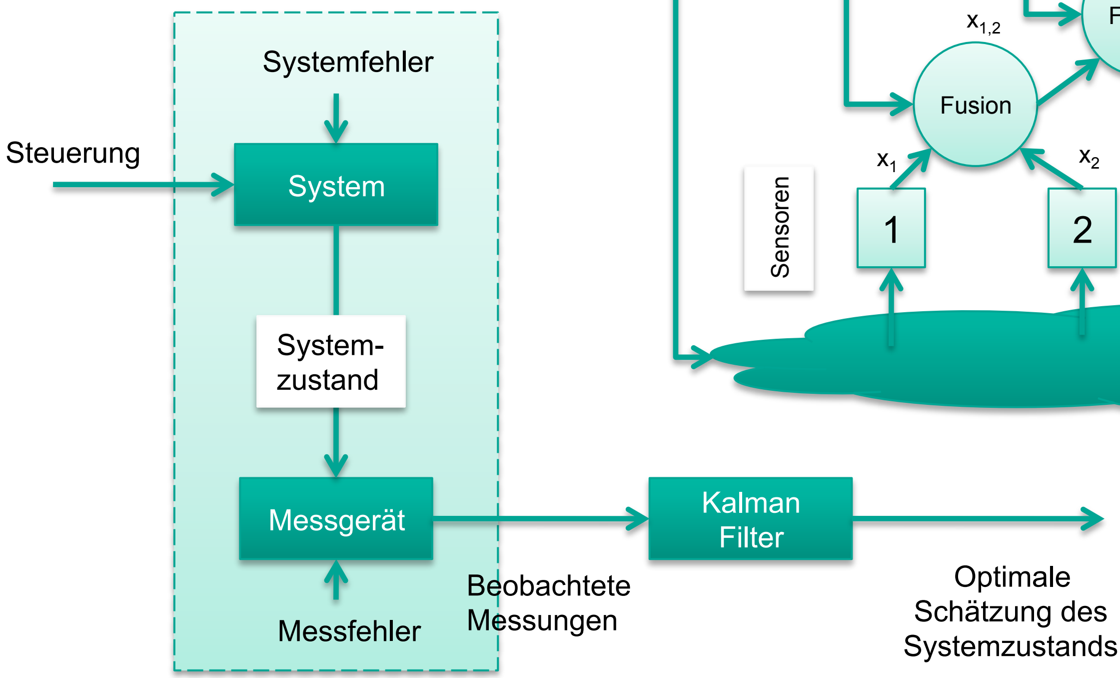




Multi-sensor Integration & Fusion

- Multi-sensor System Architectures
- Kalman Filtering
- Fuzzy-Set Theory





Historical Development I

- 1947 Servicing on Telemanipulators
- 1948 Power feedback to Telemanipulators
- 1950 NC-Maschins
- 1956 Patent on „Unimate“-Robots
- 1961 Coupling of tactile Sensors with Telemani-pulator and Computer
- 1963 First experiment in the field of image evaluation
- 1967 Control of Gripping processes by optical feedback
- 1970 Stanford Hand-Eye-System (Puzzle-Problem)
- 1972 WAVE-Robot with 2 Arms, TV-Camera, Position and Torque sensors. Integration of the data into an environmental model.
- 1973 Assembly of flat parts by evaluation of binary images (University of Nottingham)

Historical Development II

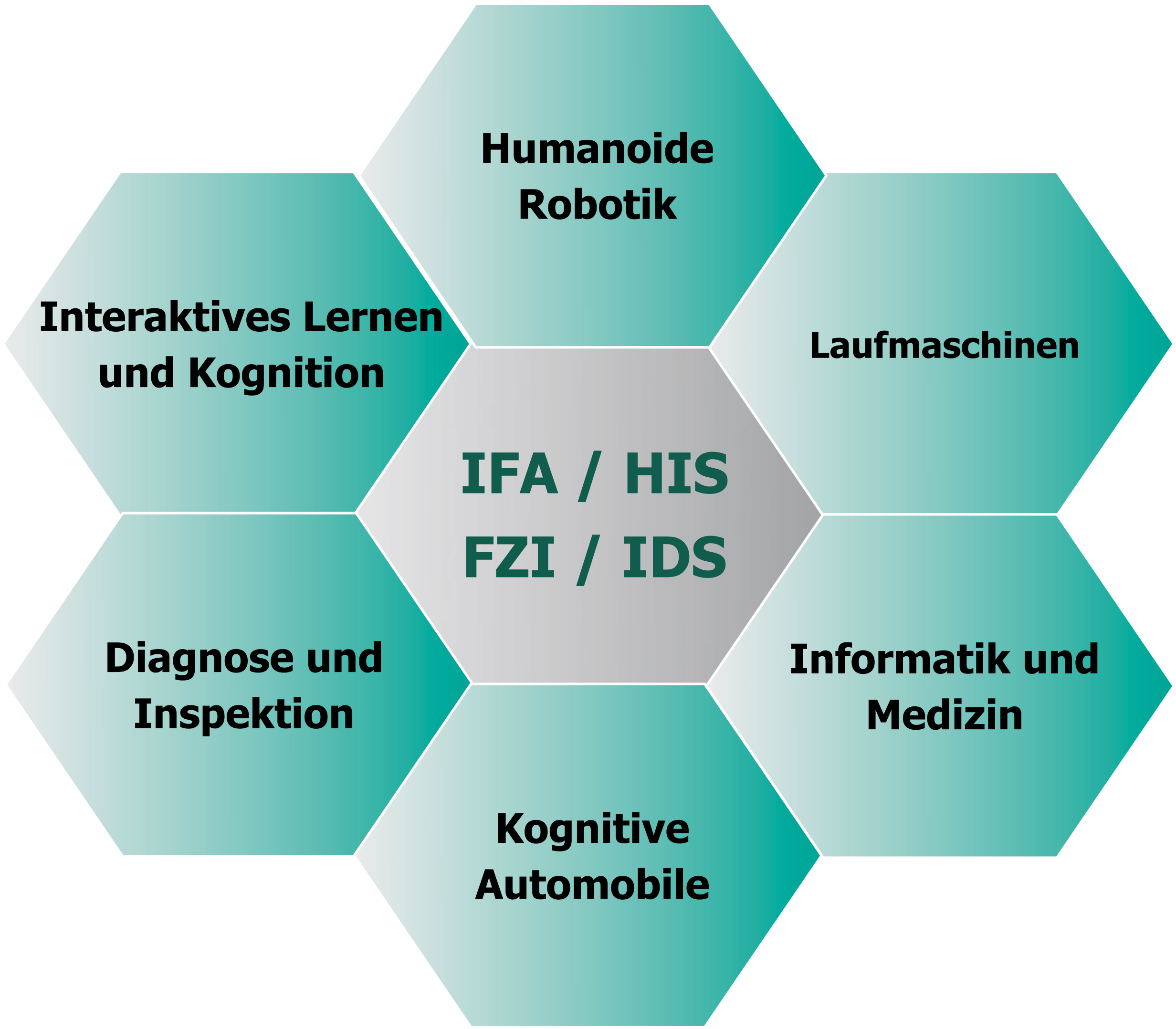
- 1996 First developments to simplified robot programming: Programming by Demonstration (PbD)
  - Data gloves
  - Magnetic Field Tracker
- 1998 First approaches to programming via Augmented Reality
  - Cyber-gloves /- suites
  - Head-Mounted-Displays
- 2000 Further developments of PbD by visual tracking systems (e.g. PhaseSpace)

  Multi-modal Human-Robot-Interaction
  - Voice recognition
  - Gesture recognition
- Since 2001 Current developments in KA tunnel robots, legged robots, mobile assistant systems, humanoid robots

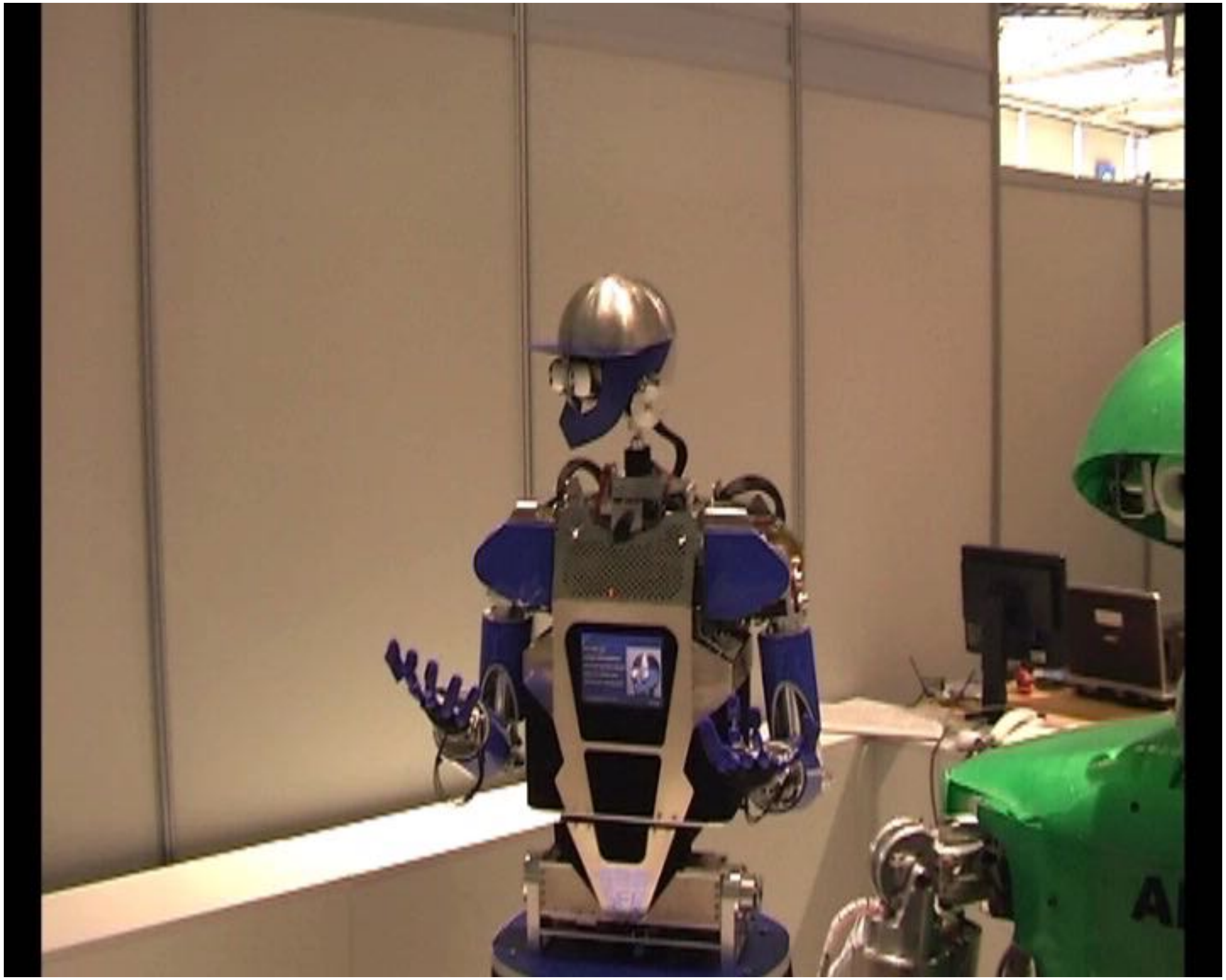
Today - Applications

- Humanoid Robots – ARMAR III & ARMAR IV
- Programming by Demonstration
- Active Scene Recognition for PbD
- Autonomous Service Robots
- Object Modeling
- Legged Robots
- Cognitive Vehicles
- Telerobotics – Nuclear power plants

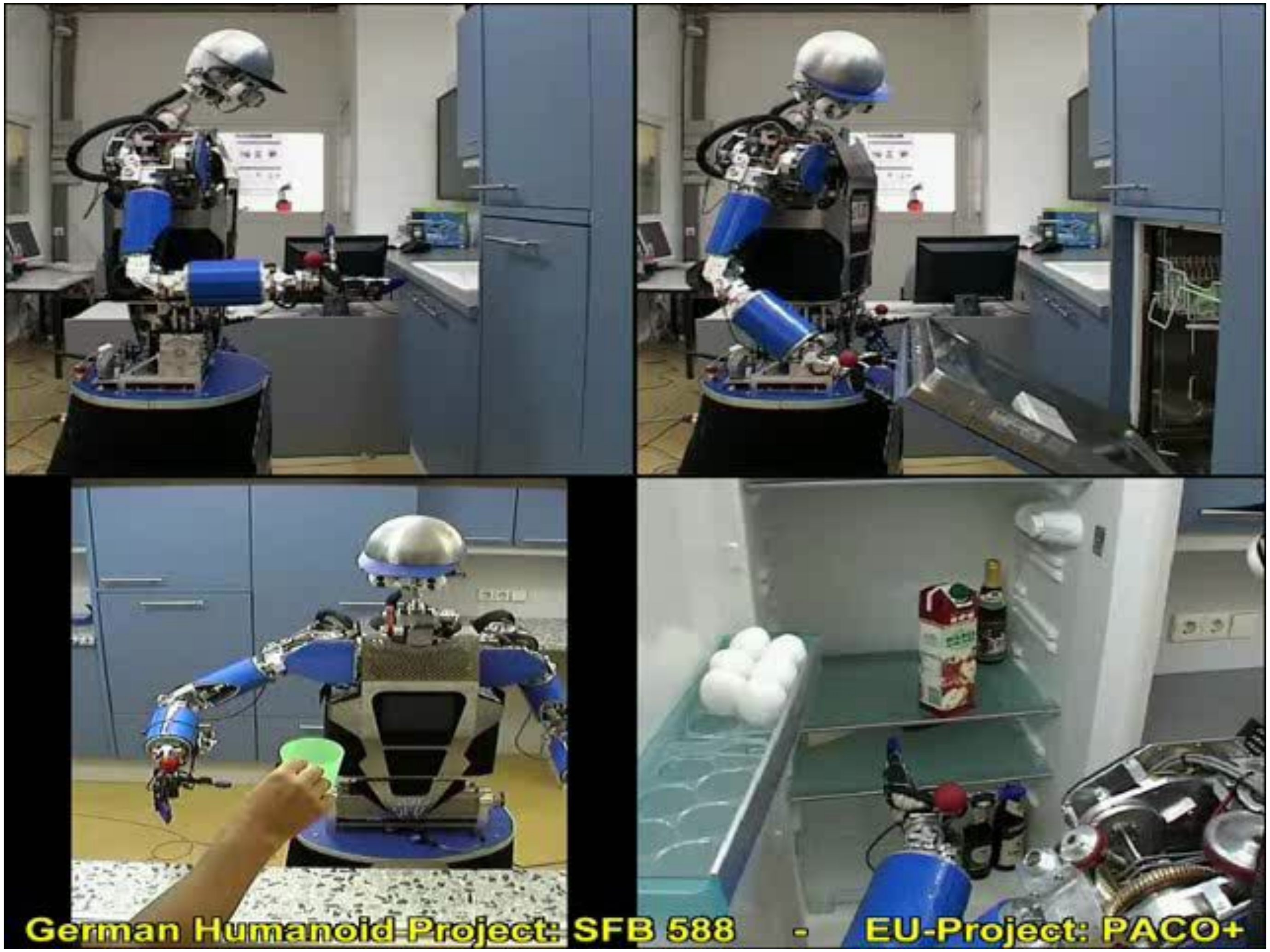
HIS/H2T: Research Areas



Humanoid Robot - ARMAR III

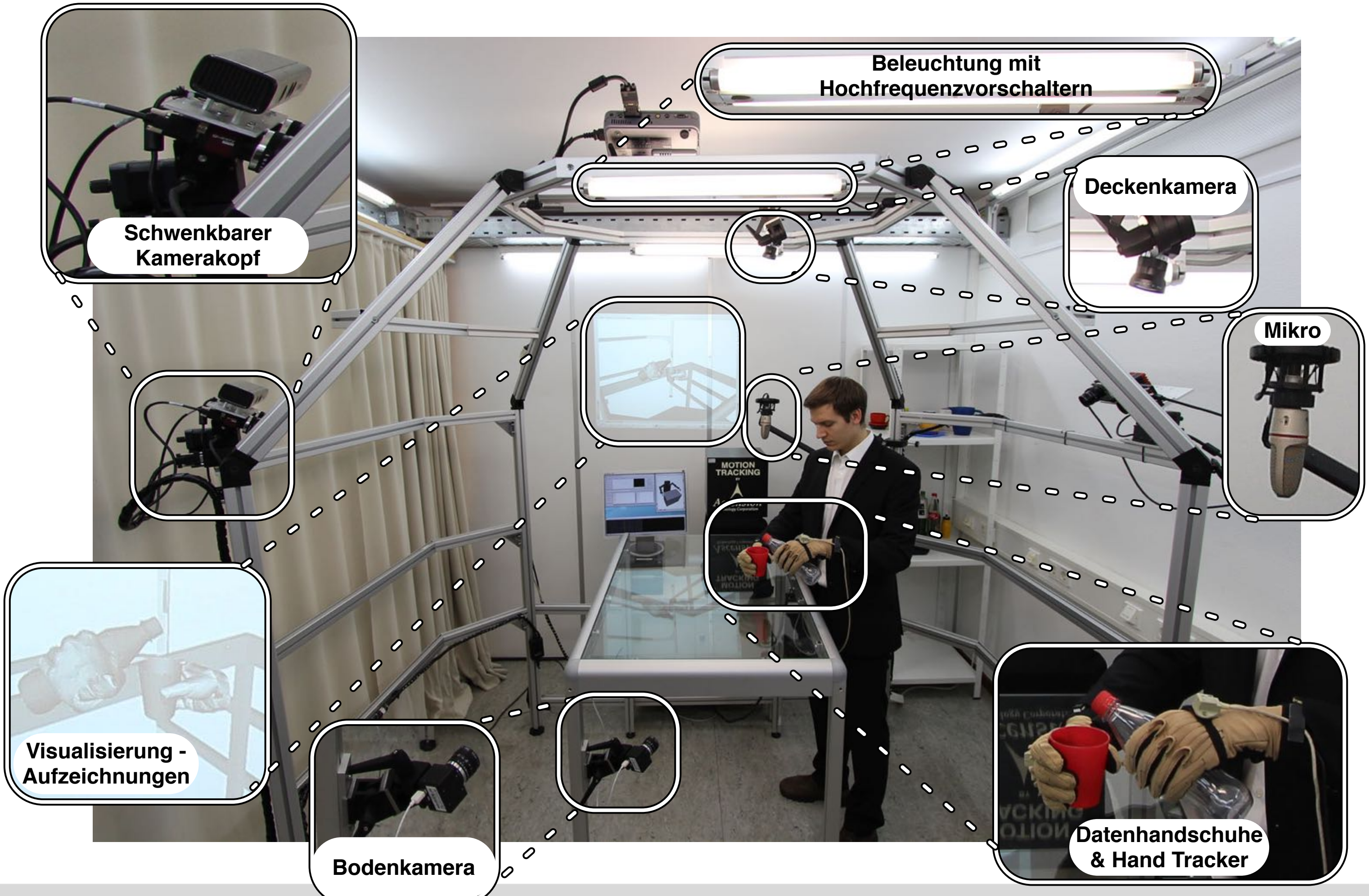


Humanoid Robot - ARMAR III



Programming by Demonstration (PbD)

- Recording of human demonstrations

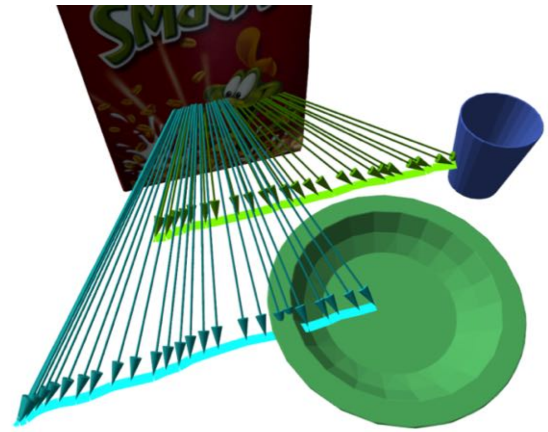


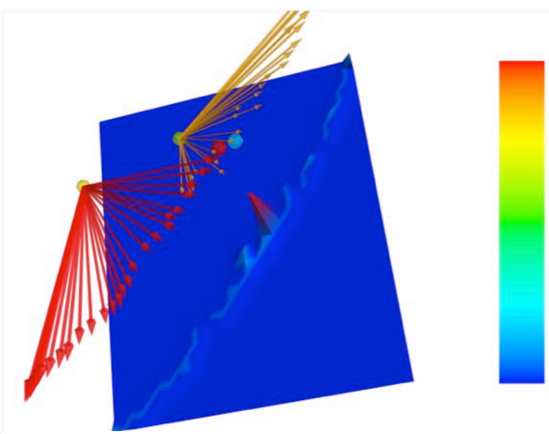
Programming by Demonstration (PbD)

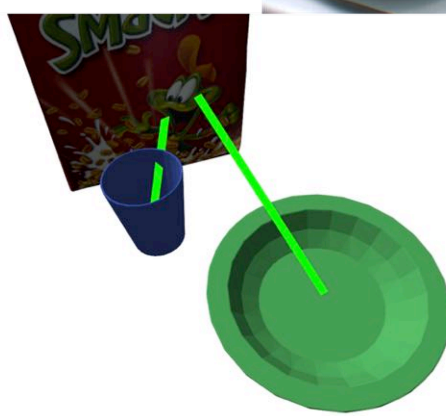
- Active & pasive accurate perception of people and scene

Active Scene Recognition for Programming by Demonstration

- Scene model: Objects with spatial relations between them
  - Hierarchical Implicit Shape Models
  - Spatial object recognition as input
- Learning of scene models from demonstrations
- Object search by learned relations for scene exploration by robots

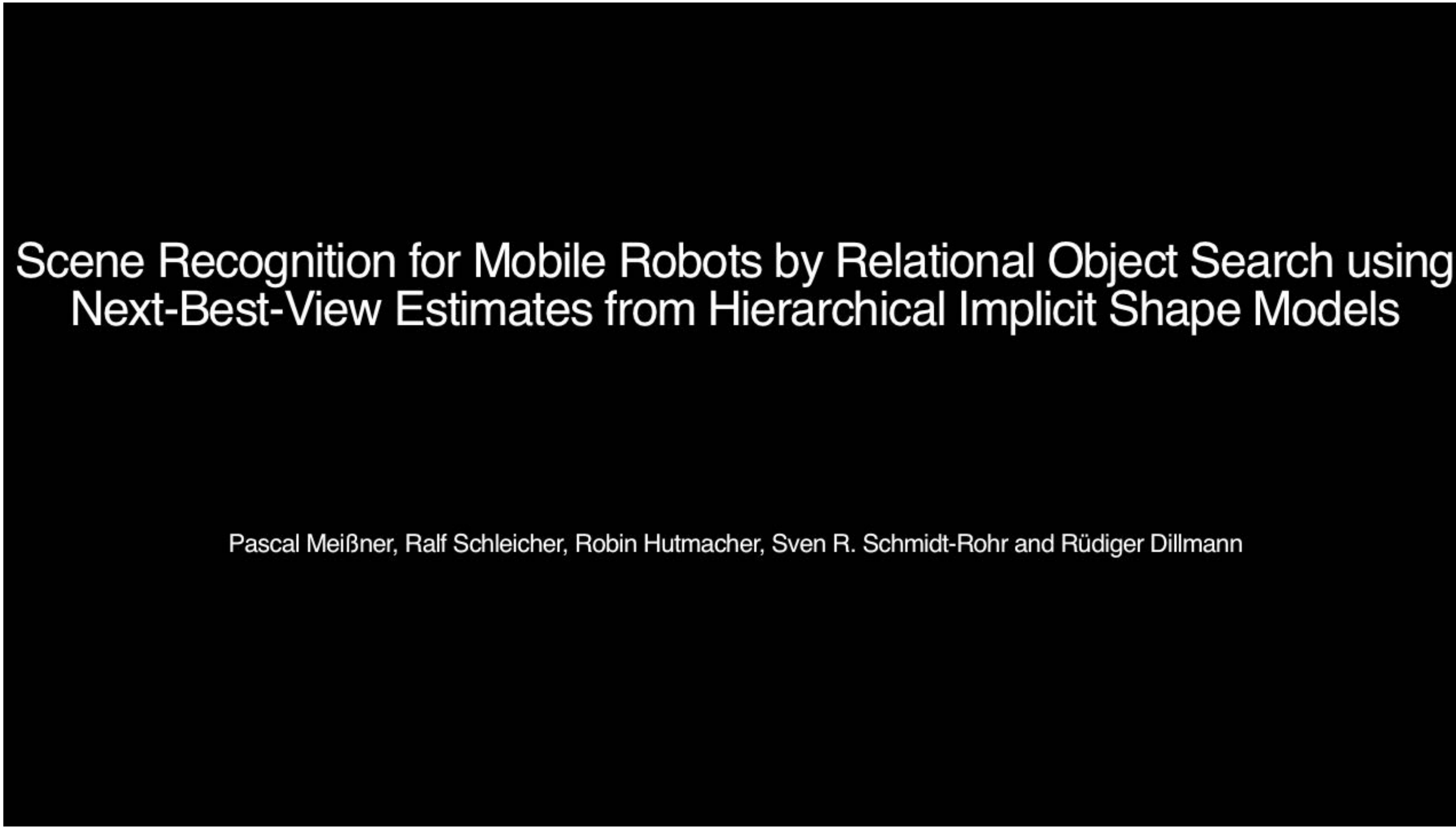






Automated Selection of Spatial Object Relations for Scene Modeling

Active Scene Recognition for Programming by Demonstration



Autonomous Service Robots

- Manipulation & Navigation
  in dynamic environments
- Use of :
  - 2D Laser scanner
  - Rotating robot head

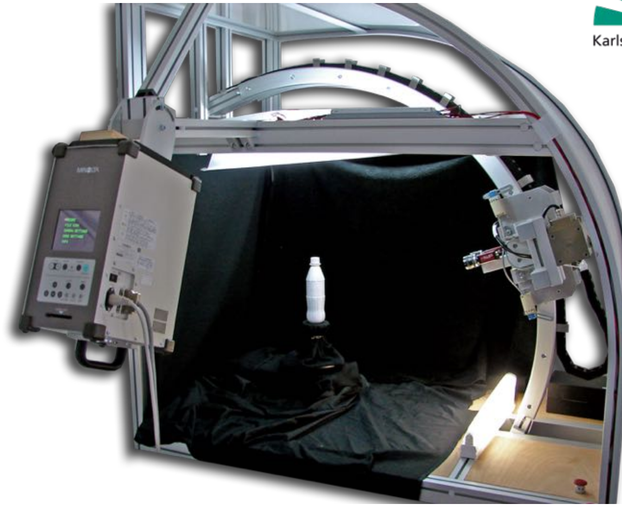
  Stereovision (Color cameras)
  & „Kinect“s
  - Force measurement
- Examples:
  - Dual-arm Robot „IMMP“ (FZI)
  - Dual-arm Robot „HOLLIE“ (FZI)

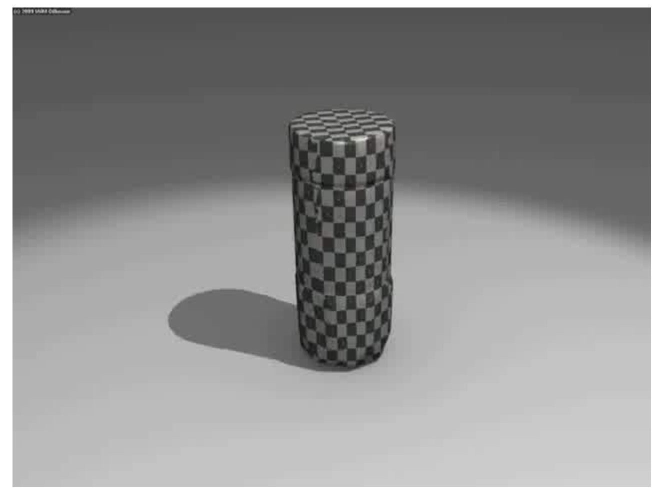
Autonomous Service Robots

- Autonomous action execution on IMMP with object perception

Object Modeling

- Semi-automatic digitization of everyday objects
- Sensors
  - Minolta Vi-900 Digitizer
  - AVT Marlin IEEE1394 Cameras
- Turntable and camera light for full automatic object and sensor positioning
- Adjustable 3-Point-Light setup
- Output
  - 3D Geometry
  - Texture
  - Object views
- Used in object recognition, localization and grasp planning as well as visualization





Legged Robots

Walking in unstructured terrains:

- 3D – Foot force sensors
- Inclination sensor with earth magnetic field measurement
- Panoramic camera

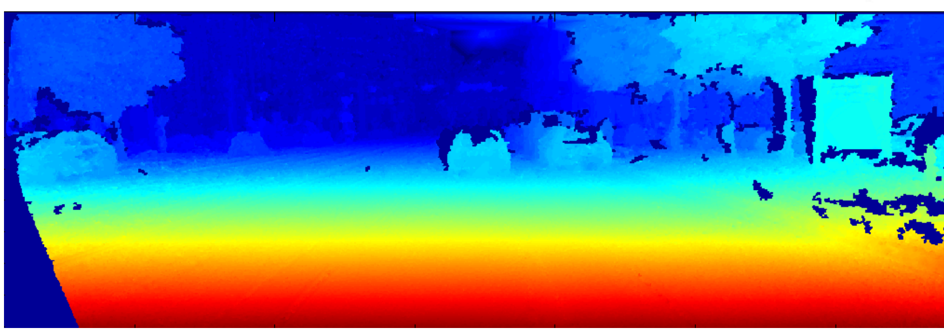
Legged robots
Lauron I, II, III, IV (FZI)

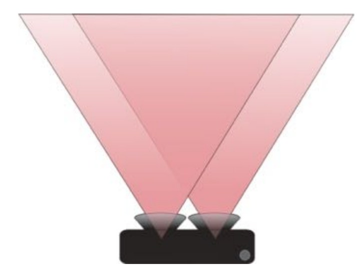
Legged Robots

Legged Robots

Cognitive Vehicles

- Probabilististic prediction and estimation of dynamic obstacles:
  - Wide baseline stereo camera system
  - Rotating laser *Velodyne* LIDAR 64
  - GPS
  - Inertial sensor





Telerobotic

Using the example of the Nuclear Technology Assistance

- Manipulation monitoring – radiation resistant cameras
- Radio remote control - per Masterarm
- Rotating SICK (RoSi) - 3D-Scene analysis

Sensors in Robotics

Sensor Technology

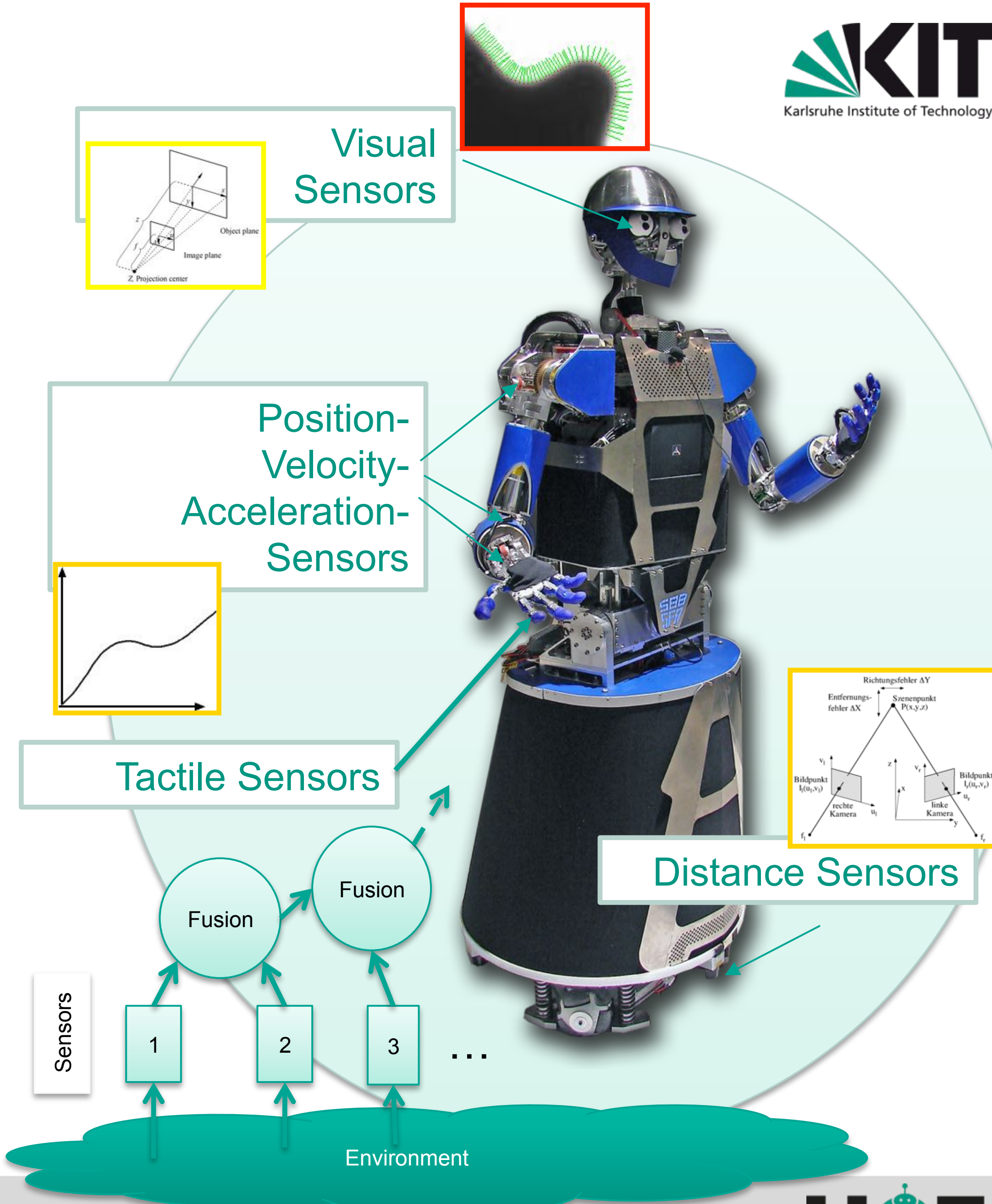
- Internal Sensors

- External Sensors

Sensor Modeling

Digitale Signal Processing

Sensor Integration and Fusion



It gets started next week!

Questions?