Concepts, Tools and Devices for Facilitating Human-Robot Interaction with Industrial Robots through Augmented Reality

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KUKA Roboter GmbH

Overview

- Introduction
  - KUKA Robot Group
  - Motivation from a broader perspective
- AR System Requirements from an industrial standpoint
- KUKA AR Viewer
  - Implementation
  - System Architecture
  - Human-Machine-Interface
  - Video
- User Survey
- Summary
- Outlook

KUKA Products and Services

Robot controller /
Robot software

Robot hardware

Robot controller

Customer support

Industries where KUKA Robots are used

Car manufacturers

Automotive components

Metal products

Chemicals, rubber & plastics

Printing & paper

Wood & furniture

Foodstuffs

Entertainment

Applications where KUKA Robots are used

Spot welding

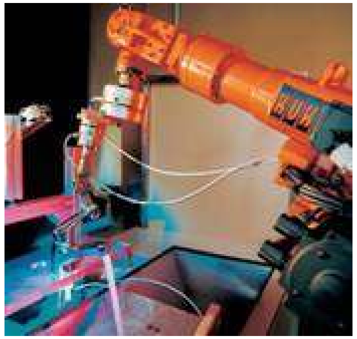
Handling

Assembling

Joining

Polishing

Inspecting



Palletizing

Machining

Corporate Headquarters

Augsburg, Bavaria, Germany


KUKA's site between Blücherstraße and Zugspitzstraße, Augsburg


Headquarter, Augsburg


Sales and Training Center



Training center at Hery-Park, Gersthofen

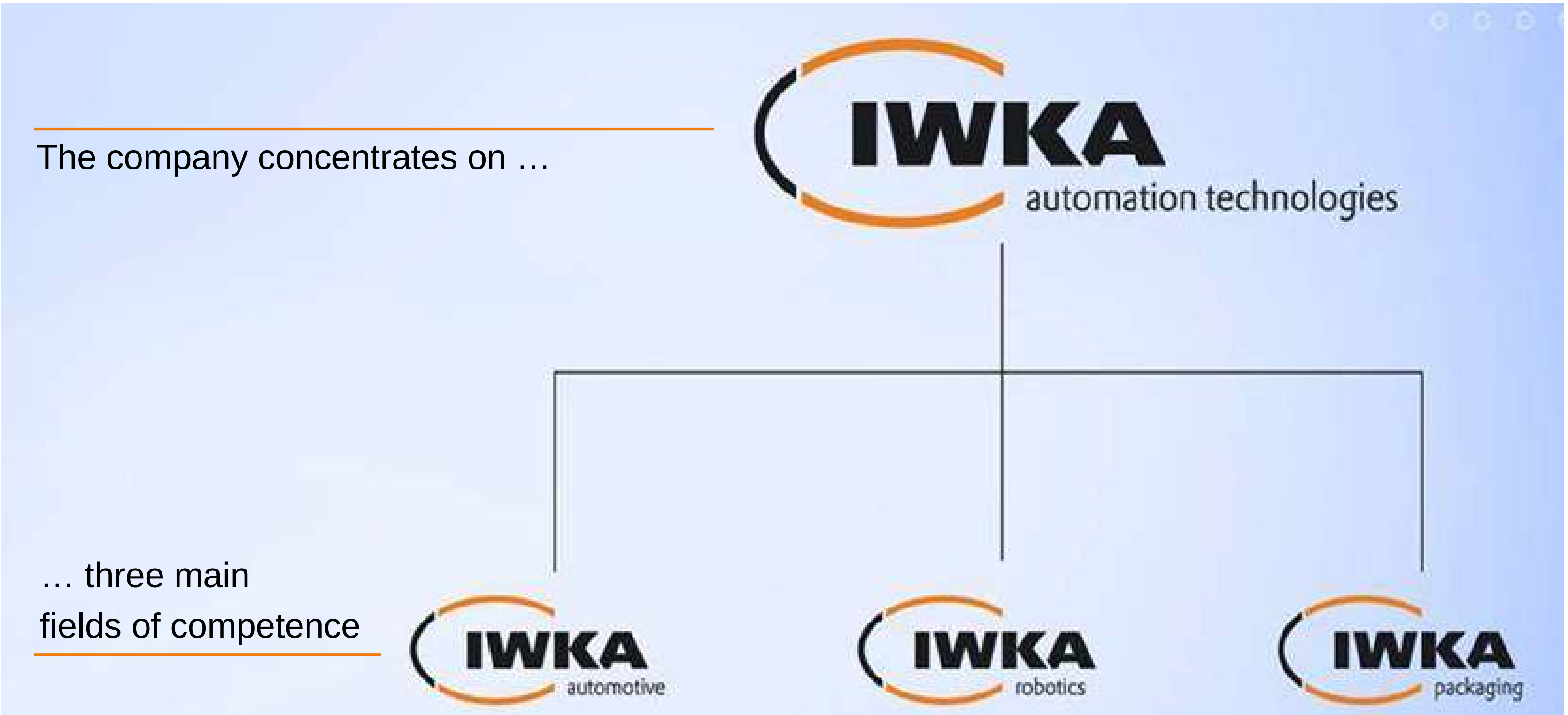

Robocoaster

KUKA

KUKA Locations Worldwide

Production of up to 8000 robots / year

IWKA Group of Companies, listed in MDAX



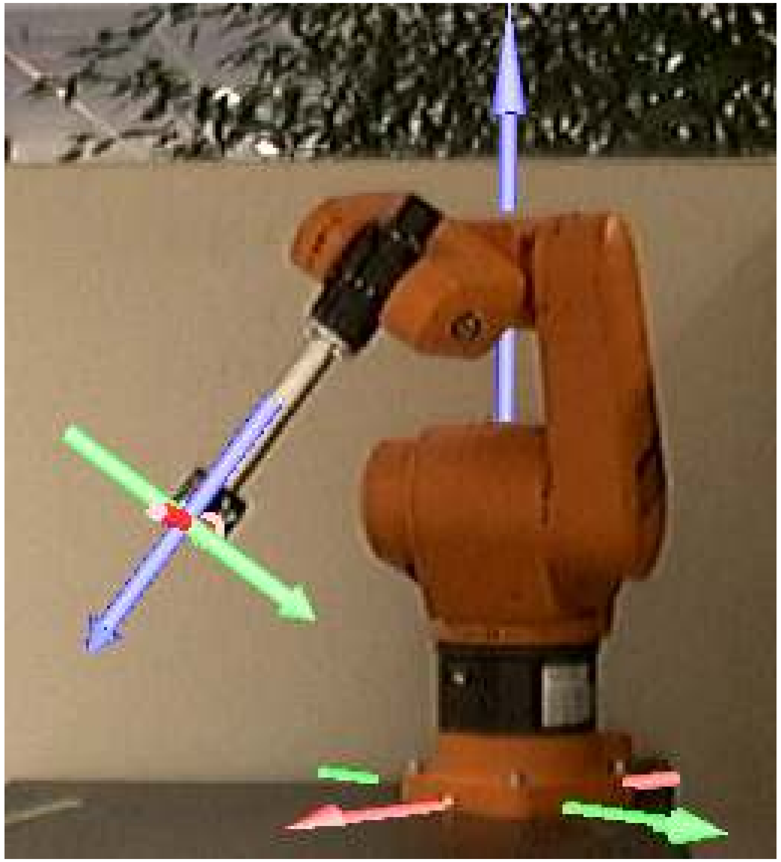
2005: Portfolio: 83 consolidated companies
Sales: 1613 Mio €
Employees: 8974

Industrial Robots – Where does KUKA want to go?

- maintain technological leadership in industrial robotics
- ensure the productivity of manufacturing industries
- provide small and medium sized enterprises with advanced robots and systems
- provide new and high-quality jobs
- key business drivers
  - technology push from IT sector
  - application pull from
    - automotive
    - electronics industries
    - general industries (future applications)

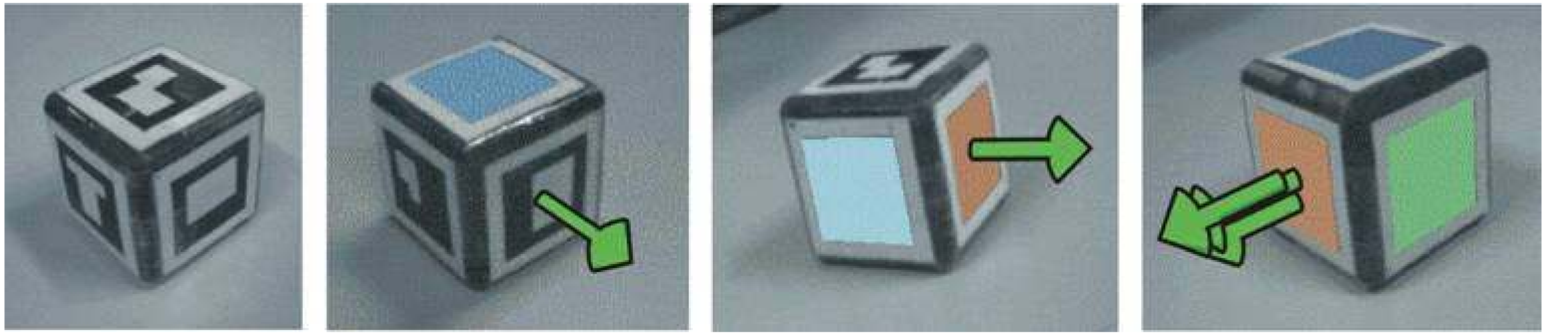
What is Augmented Reality?

- embedding of virtual information into the real world
- position virtual objects dynamically in relation to the real world
- to give the appearance that the virtual objects exist within the real world

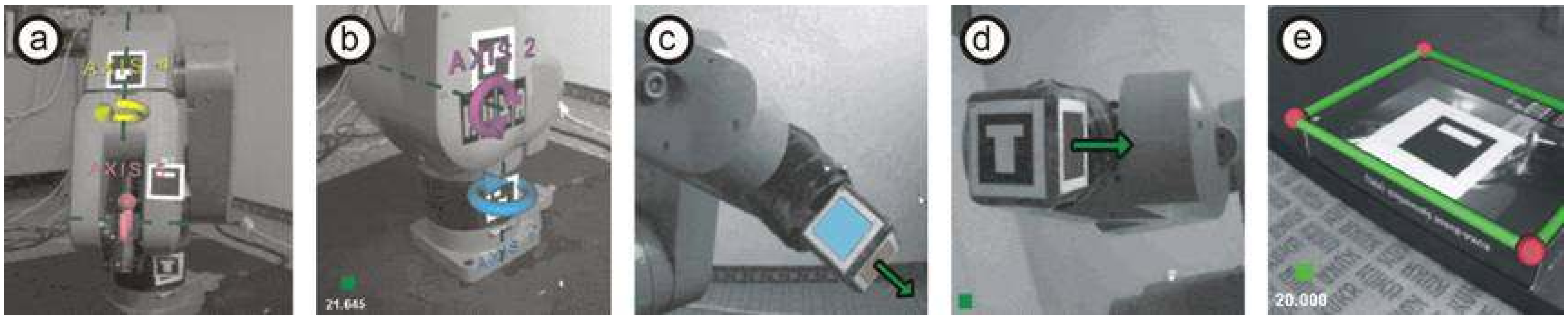


First Experiments and Results

- cubic markers from six 2-D markers



- various visualization options

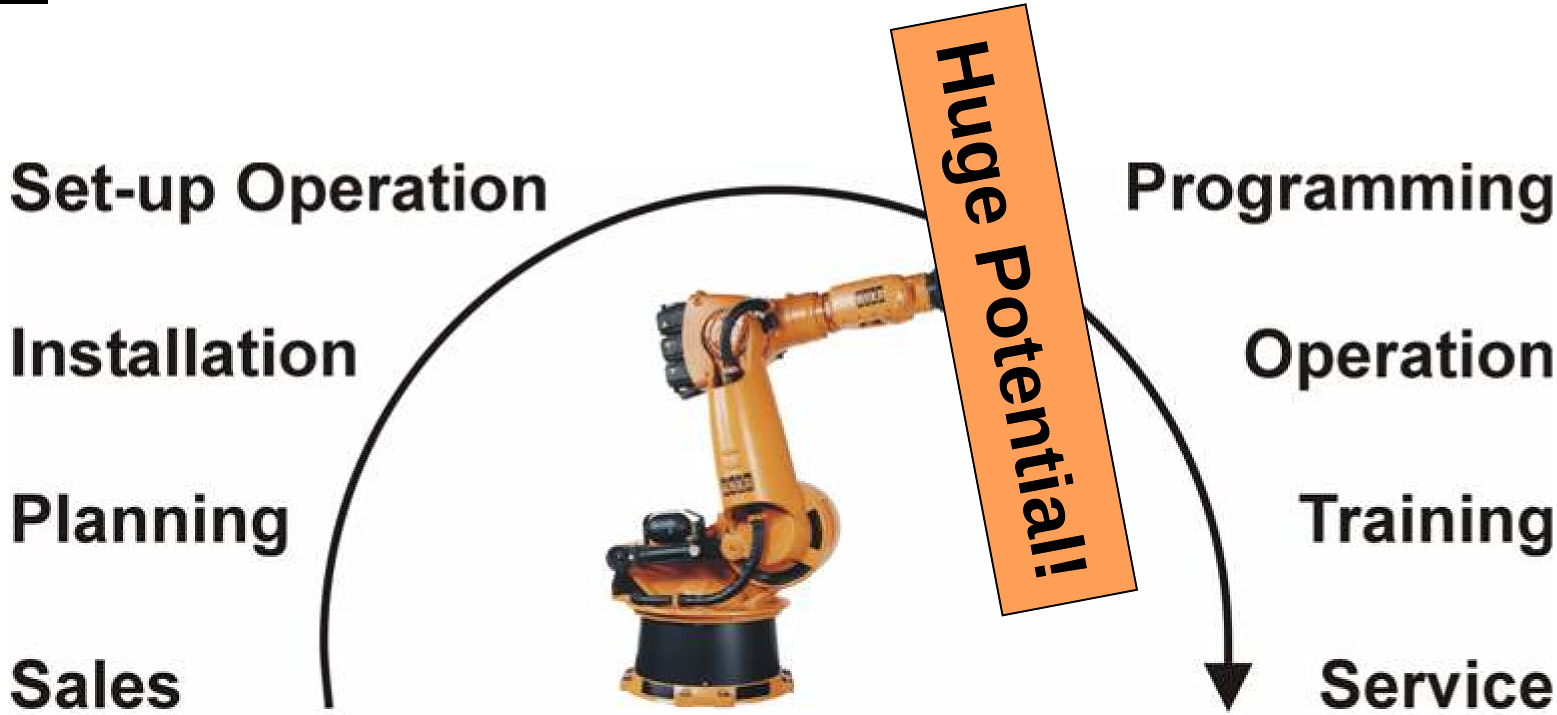


First Experiments and Results

- AR-based tutorial on how to use the 6D mouse

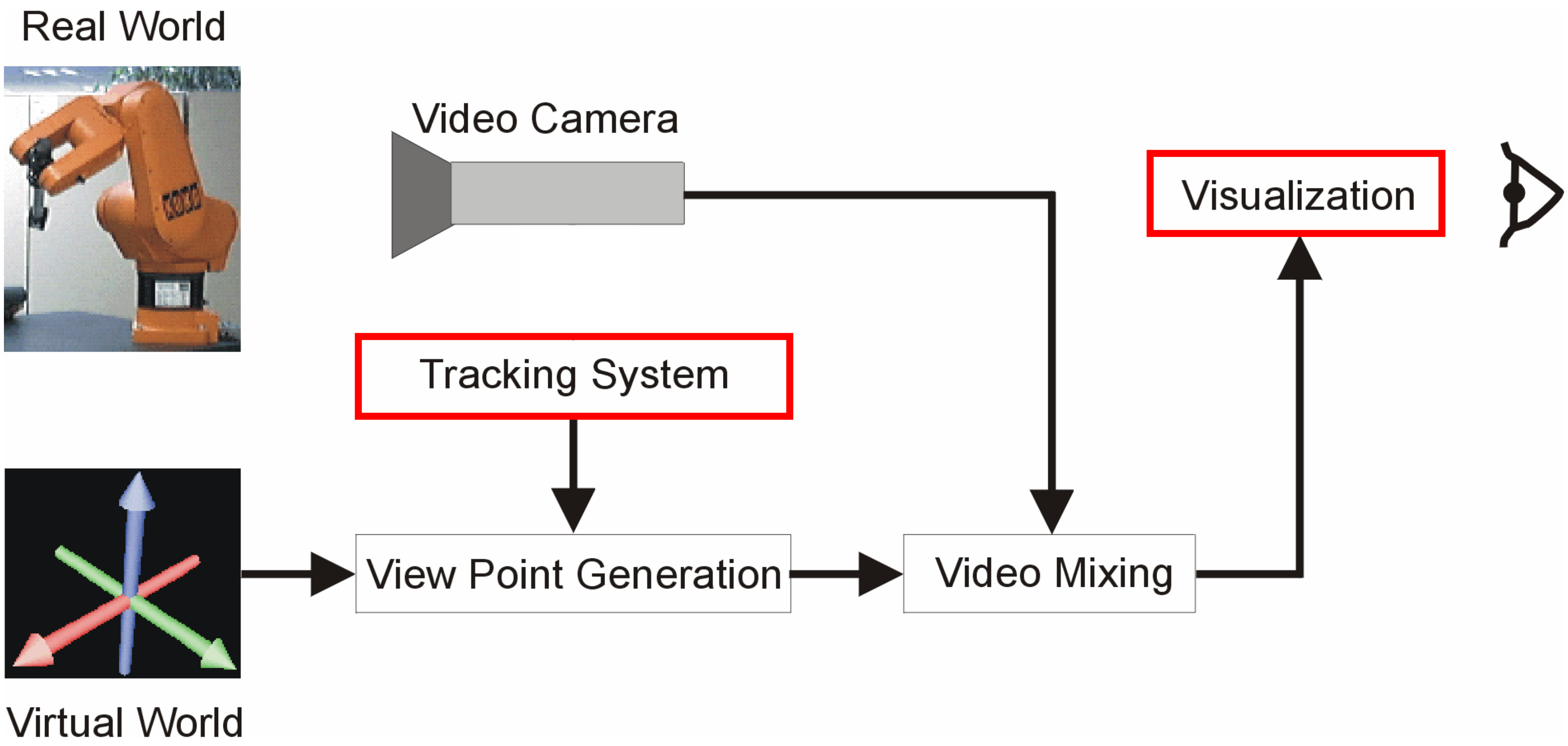
- AR-based tool for fault detection

Application Areas for KUKA



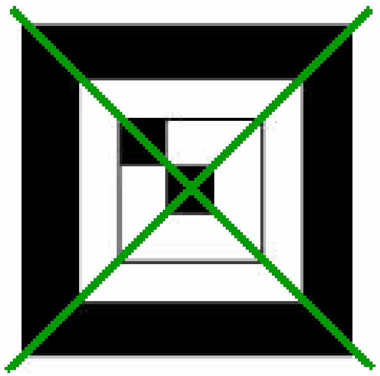
Augmented Reality can make life easier throughout the life cycle of a robot!

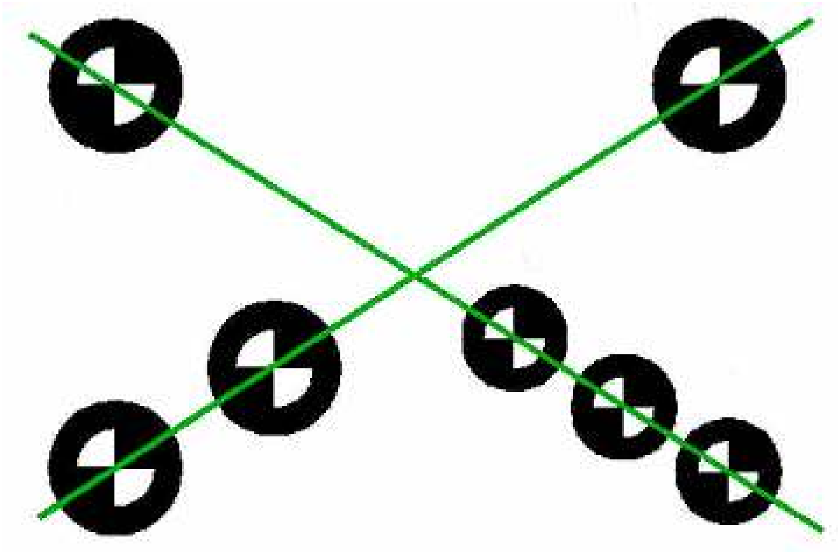
Working Principle – Key Components



Optical Tracking

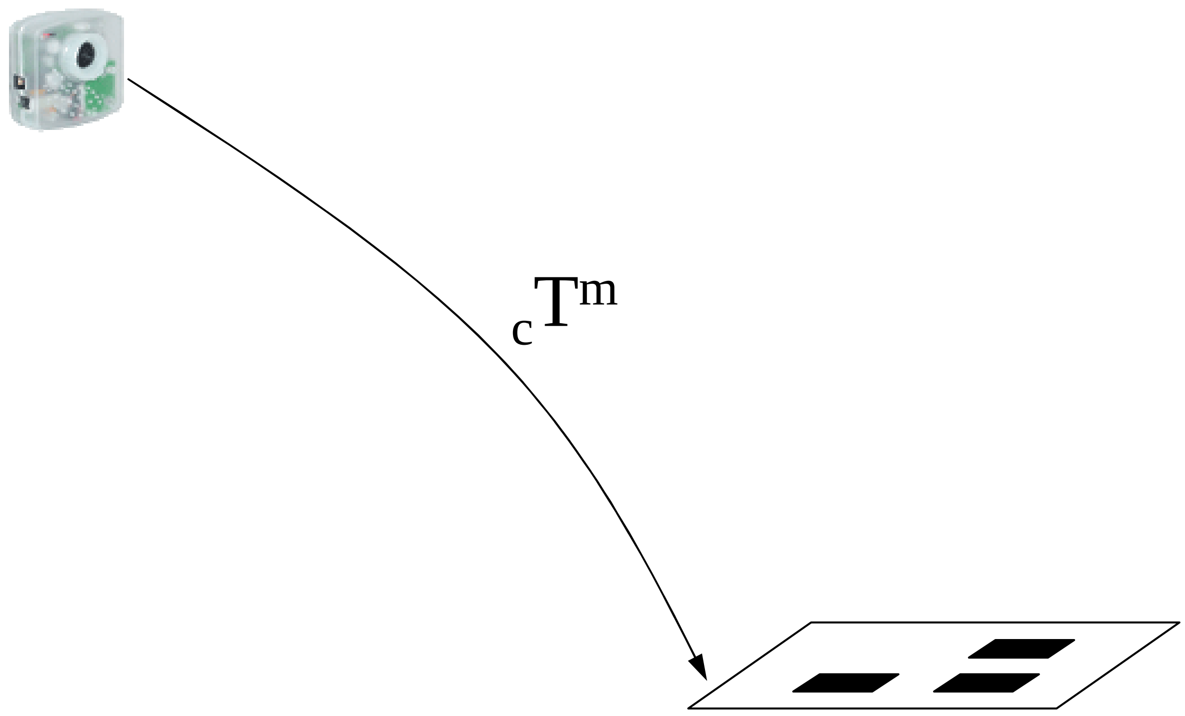
- markers placed in the real world
- AR-Software determines centre of markers
- virtual world is fixed relative to the real world





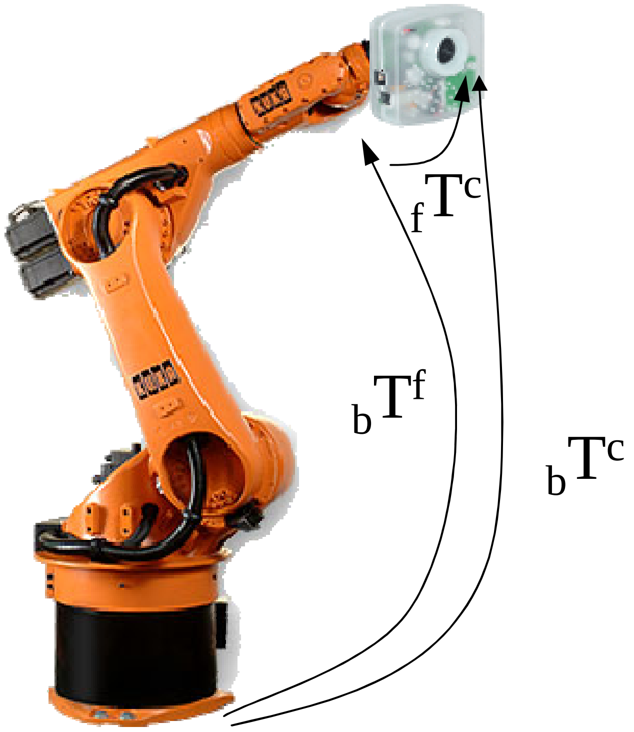
Optical tracking

- tracking 6-D pose of camera



Mechanical tracking

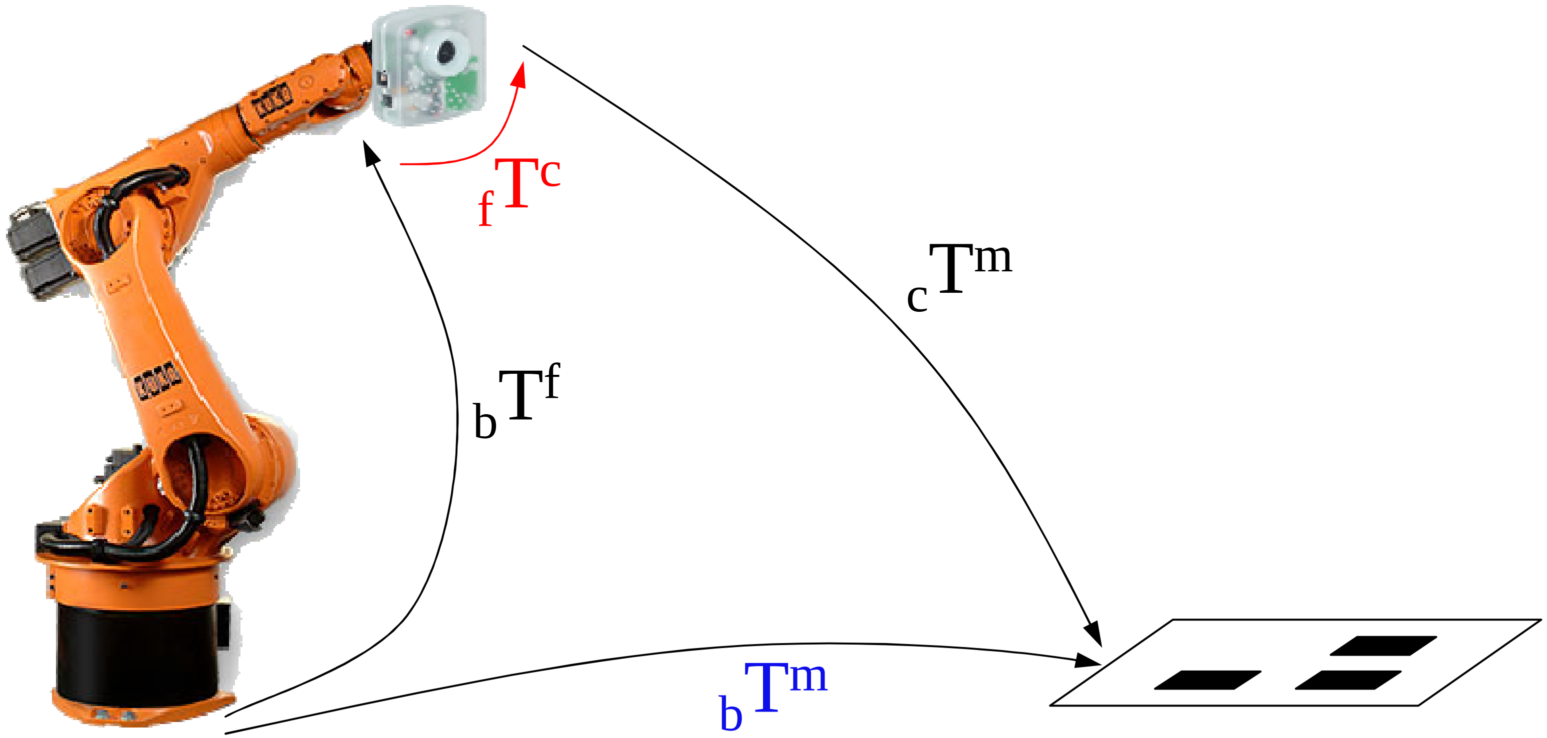
- tracking 6-D pose of camera
  - by using a robot system and knowledge of the position of robot’s axes and kinematic transformations
  - no need of markers during operation



but $_fT^c$ is unknown

Set-up of Mechanical Tracking

- use marker tracking to provide missing transformation ${}_{f}T^{c}$



- method to obtain ${}_{b}T^{m}$:
  perform hand-eye calibration and obtain marker position at the same time

Registering the Position of the Robot

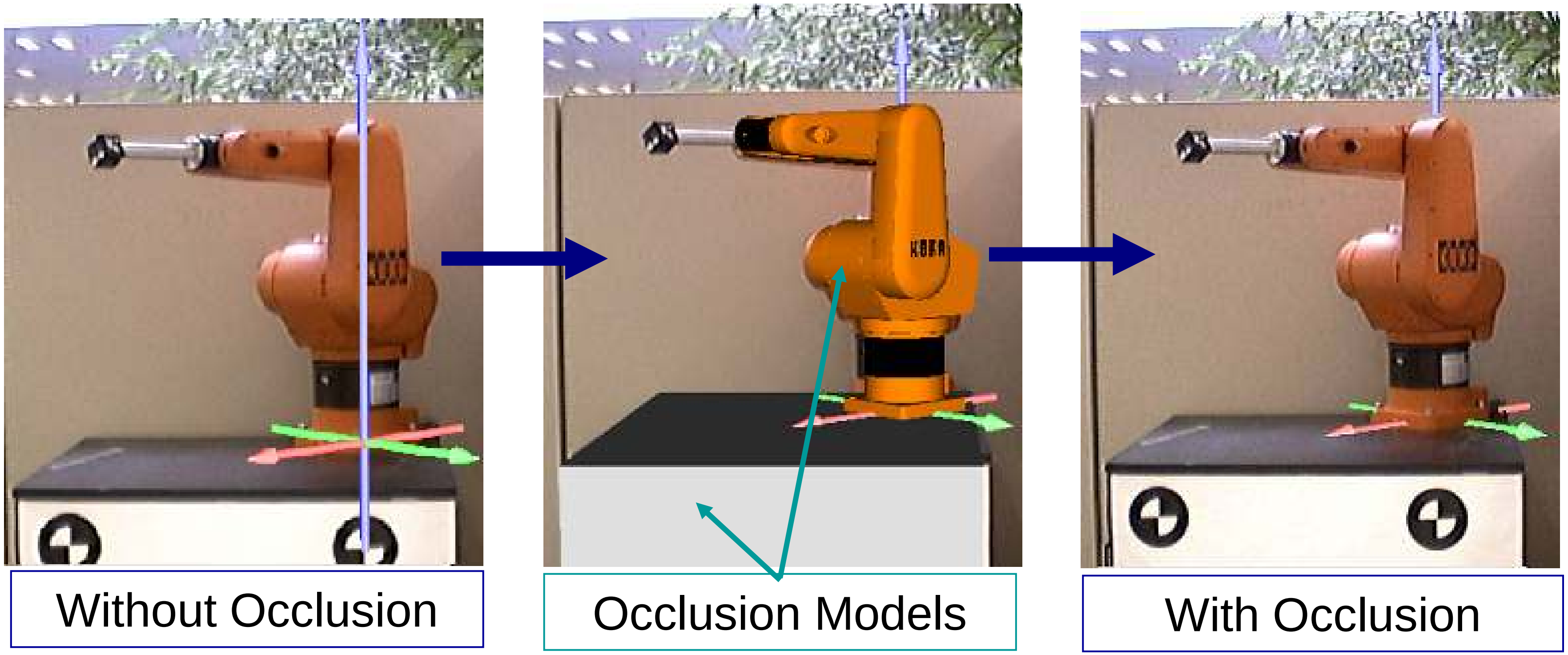
- use of hand-eye techniques (e.g. Tsai, Lenz)
- principle set-up steps:
  - mount camera at the robot flange or tool (arbitrary pose)
  - move the robot to several different positions, so that the marker is always in the camera image
  - positions of the robot and tracking values are gathered
  - a hand-eye algorithm is run with the acquired information
- result:
  - known position of the robot in the marker coordinate system
    <u>and</u>
  - know position of the camera in the robot coordinate system

Setting up the Scene for an AR Scenario

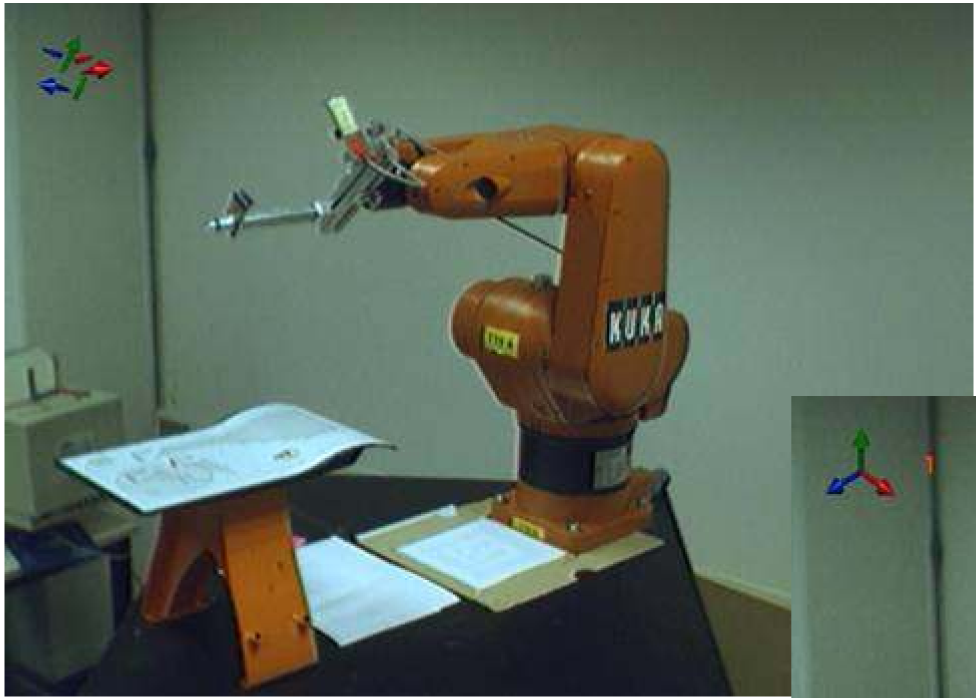
- requirements:
  - 3-D models of invisible objects to display robot-internal information, e.g.:
    - coordinate systems
    - program points
  - 3-D models of all real objects for computing occlusions
    - robot
    - all other objects within the robot cell
  - registration of 3-D models with the real world, i.e.:
    - knowing the position of the real-world objects
    - relative to the world coordinate system
  - user needs to be supported to be able to set-up the system (!)

Occlusion Models

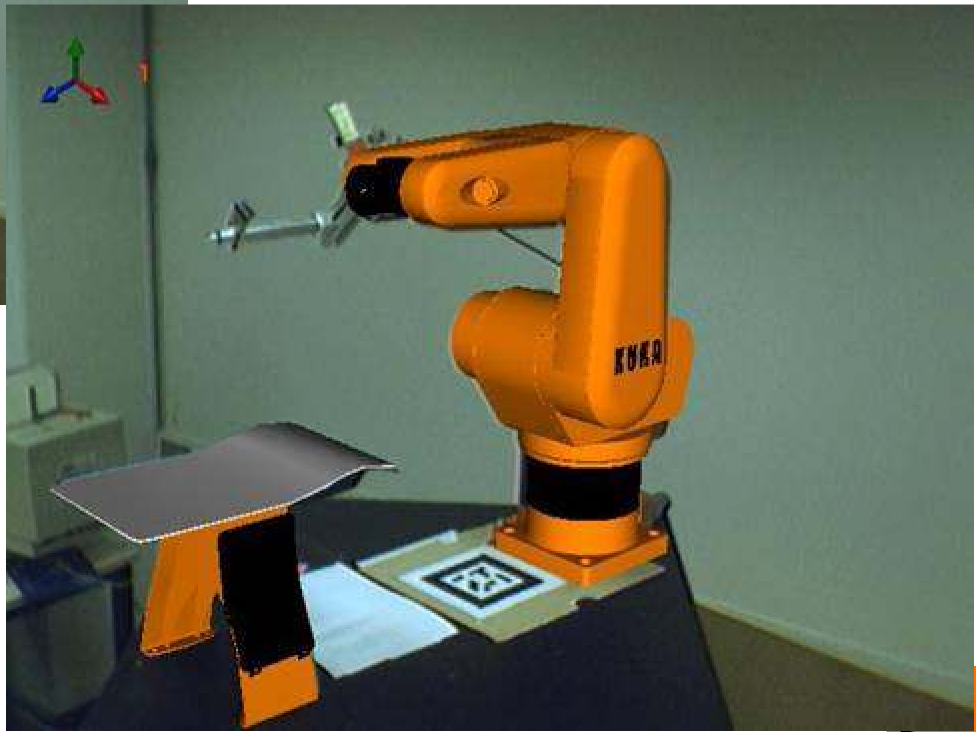
- Hide all or part of a virtual object when the line of sight is blocked by a real world object
- Requires 3D modeling of real world objects



Setting up the Scene for an AR Scenario



we have



we need

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Registering the Positions of Scene Objects

- two methods possible:
  - if virtual models of real-world objects are not provided:
    (1) define object vertices and construct a convex hull
  - if virtual models of real-world objects are provided
    (2) move virtual models with the mouse to align them with the images of the corresponding real objects

Details of Implementation

- Monitor based visualization
  - rapid development
  - robust
  - cost effective

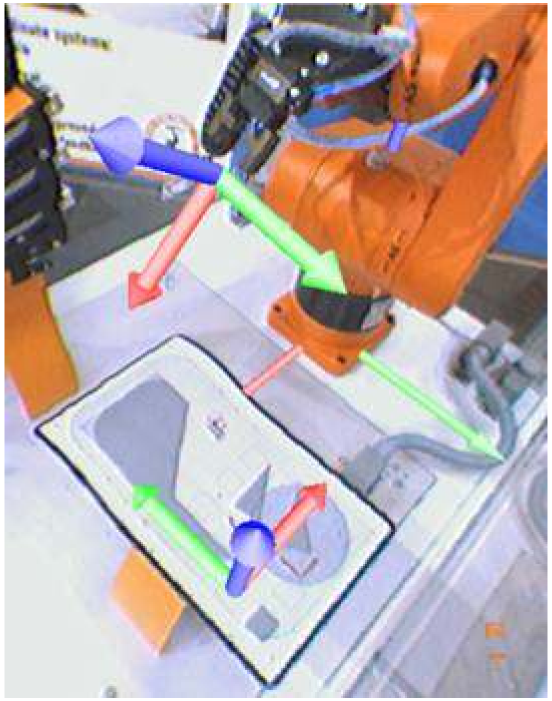
- Optical tracking system
  - 6 degrees of freedom, high accurac
  - requires the use of markers
- Mechanical tracking system
  - 6 degrees of freedom, high accurac
  - limited range
- Software
  - Metaio Augmented Solutions AR ActiveX Control
  - KUKA Roboter Controller Software KRC 5.x
  - KUKA Augmented Reality Viewer

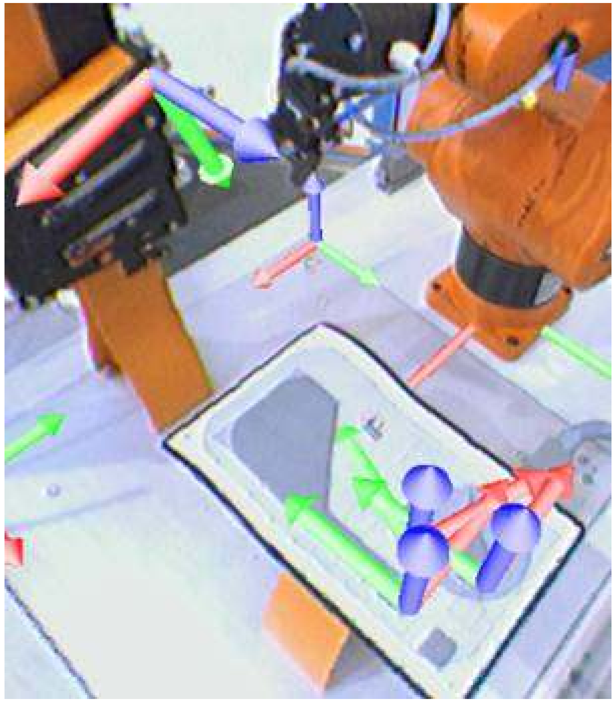
KUKA AR Viewer

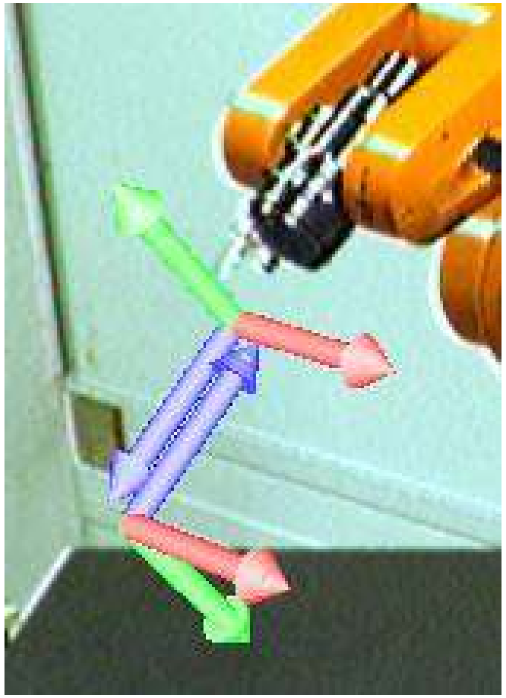
- Visualization of operating and programming information
- Test framework for a variety of system architecture concepts

KUKA AR Viewer – Coordinate Systems

- world
- multiple bases
- multiple tools

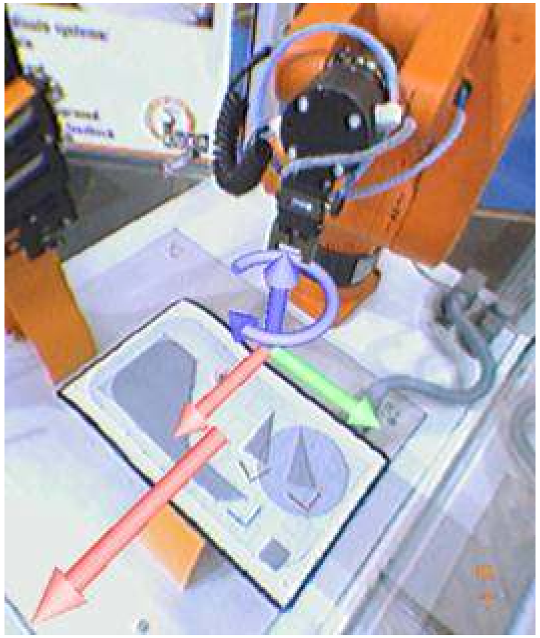






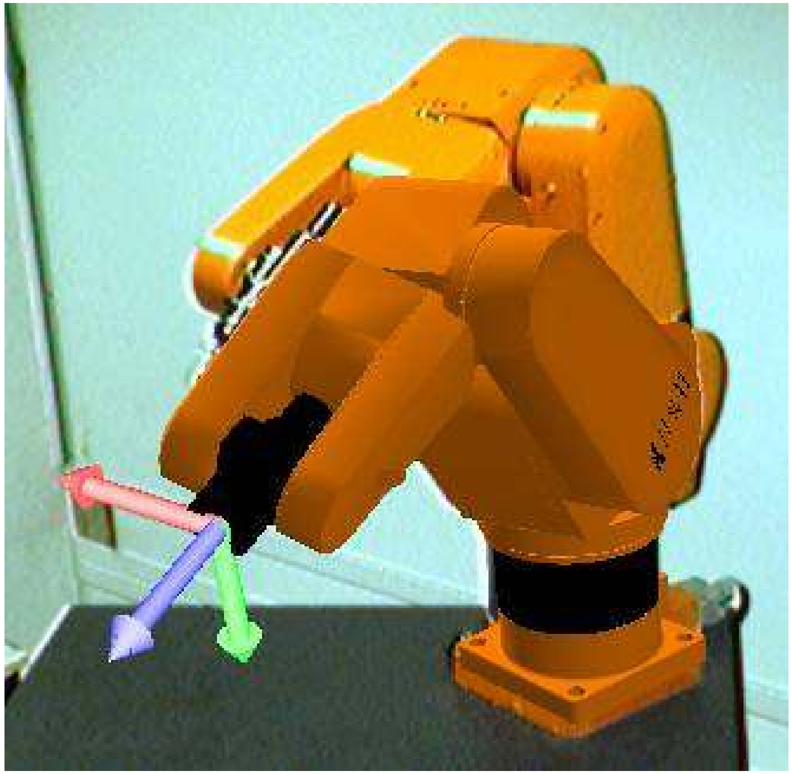
KUKA AR Viewer – Movement Arrows

- direction of Cartesian movement displayed at
  - origin of reference coordinate system
  - TCP
- axis specific movement arrows
- works with jog keys and 6D mouse



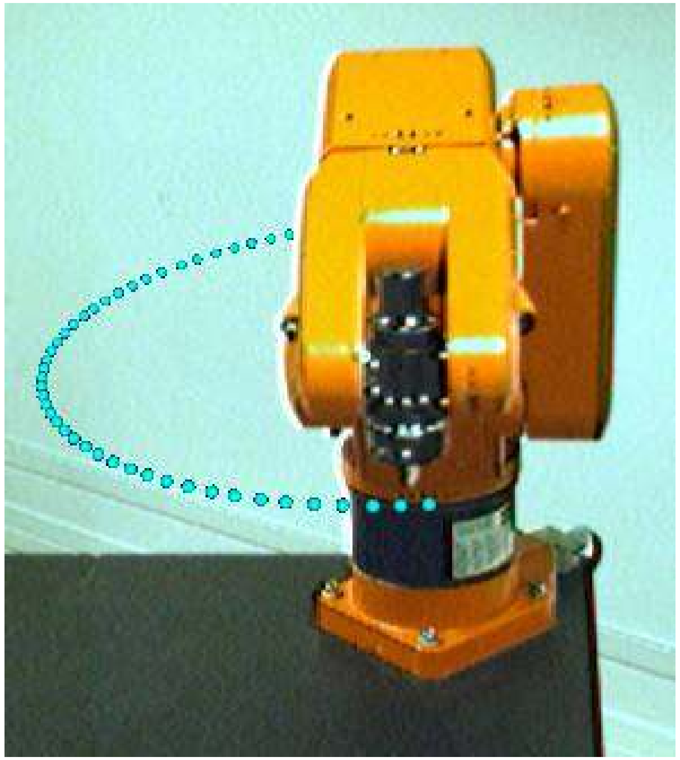
KUKA AR Viewer – Simulation Modes

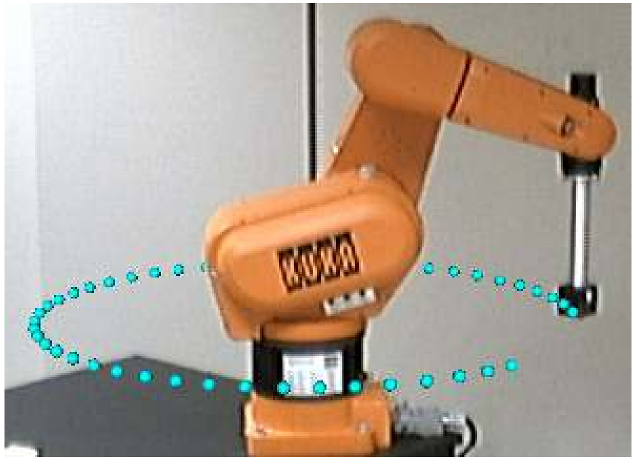
- movements of robot are simulated on the shop floor
  - without altering the functionalities of teach pendant and robot controller
- robot simulation
  - test run before real program execution
  - testing for plausibility
  - simple collisions checking
- key press simulation (for teach pendant)
  - „what happened if I pressed this button...“
  - robot does not move
  - movement arrows are visualized



KUKA AR Viewer – Path Trace

- visualization of robot path by tracing the TCP
  - TCP recording over time
    - continuously
    - intermittent
  - show / hide traced points
  - distance between recorded points
    - equal distance in space
    - equal distance in time

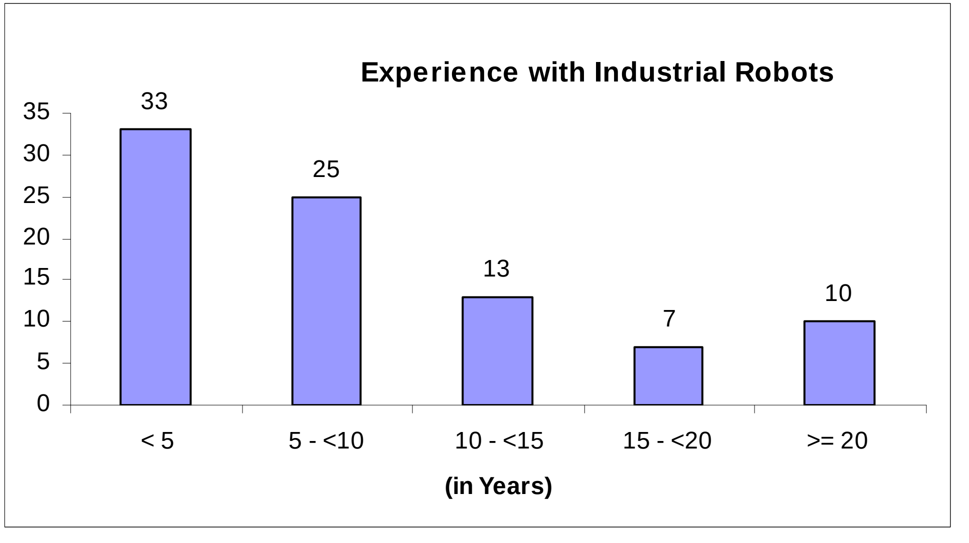




Video KR3 Robot Training Cell

User Survey

- KUKA College
  - robot training classes
  - survey preparation
- Automatica 2004
  - 4 days
  - 100 filled-out questionnaires
  - estimated number
    of interested visitors: 400-500



User Survey

AR could help me
understand robot training better

Yes	No
97.9%	2.1%

User Survey

AR could help me
with my day-to-day work with the robot

Yes	No
82.1%	17.9%

Summary

- Augmented Reality holds great potential to improve human-robot interaction
- First prototype: KUKA AR Viewer
  - various visualization and simulation options
  - instantaneous / real-time visual feedback
- Augmented Reality is especially useful for robot training:
  - visualization of coordinate systems, robot motions and path information within the *real* robot cell
  - simulation of robot motions before their actual execution
  - gain an understanding for using the different reference coordinate systems
- User survey with encouraging results

Thank you for your attention!

Questions?

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