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

Training center at Hery-Park, Gersthofen

Robocoaster

Headquarter, Augsburg

Sales and Training Center
KUKA Locations Worldwide

Production of up to 8000 robots / year
IWKA Group of Companies, listed in MDAX

The company concentrates on …

... three main fields of competence

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

Set-up Operation
Installation
Planning
Sales
Programming
Operation
Training
Service

Augmented Reality can make life easier throughout the life cycle of a robot!
Working Principle – Key Components

Real World

Video Camera

Tracking System

View Point Generation → Video Mixing

Visualization

Virtual World
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

\[ bT^c \]

\[ fT^c \]

\[ T_f \]

\[ T_c \]
Set-up of Mechanical Tracking

- use marker tracking to provide missing transformation $f^Tc$

- method to obtain $b^Tm$:
  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
  - know position of the camera in the robot coordinate system
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
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 accuracy
  - requires the use of markers

- Mechanical tracking system
  - 6 degrees of freedom, high accuracy
  - 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

![Experience with Industrial Robots](chart.png)
AR could help me understand robot training better

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<tr>
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<td>No</td>
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<tr>
<td>97.9%</td>
<td>2.1%</td>
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AR could help me with my day-to-day work with the robot

<table>
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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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