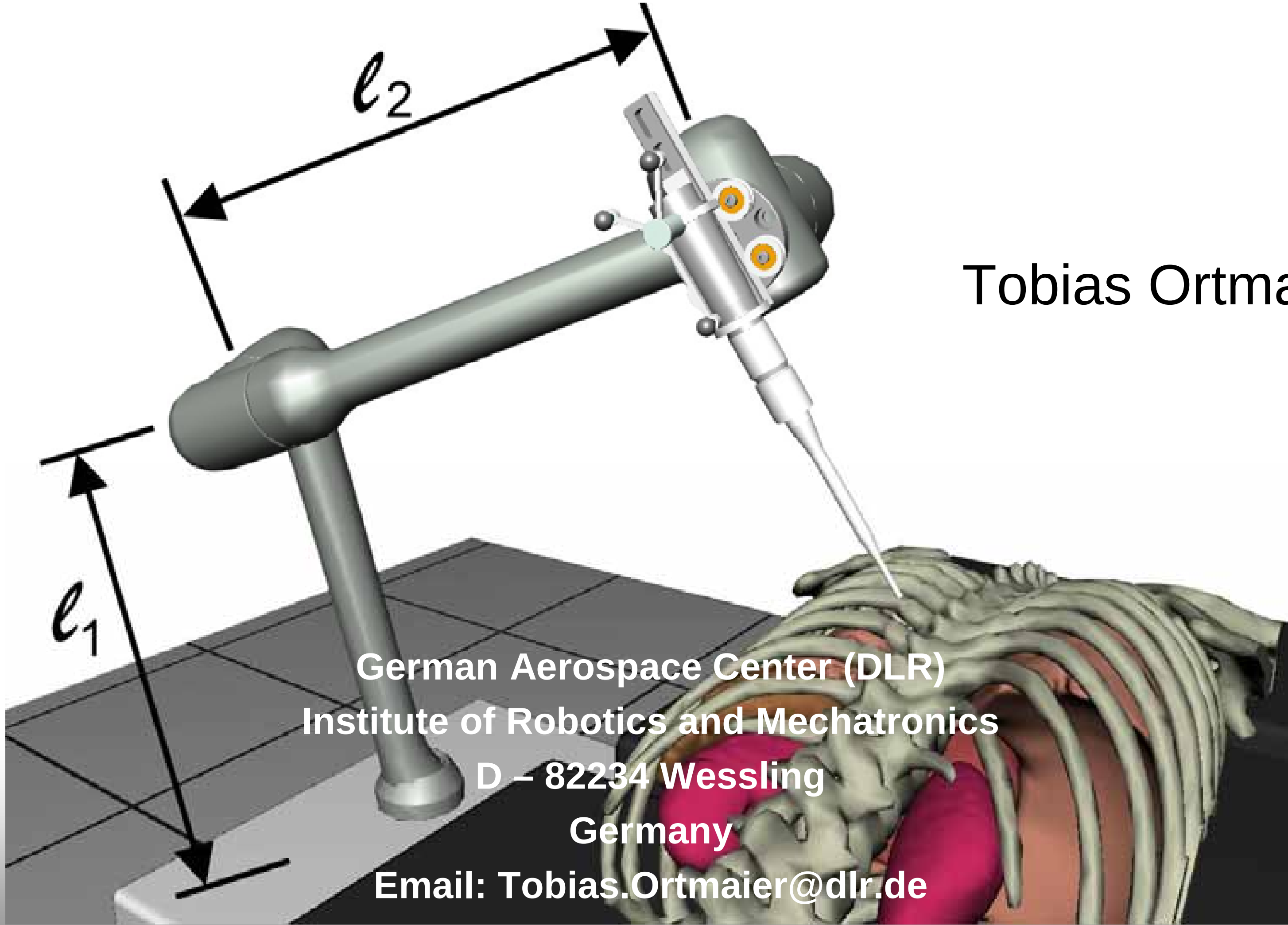
KineMedic

Robot Assisted Placement of Pedicle Screws

A “Hands-On-Robotics” Approach



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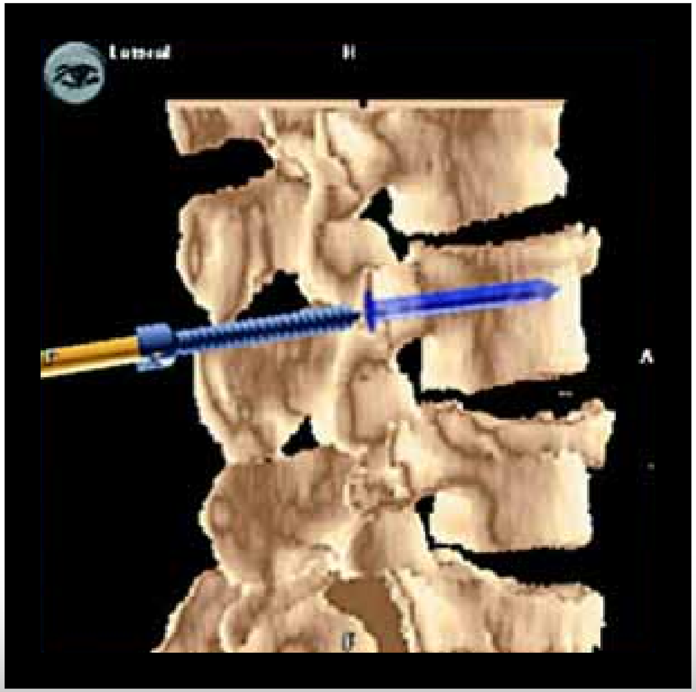
DLR

Overview

1. Application and concept
2. Design requirements
3. Robot components
4. Summary and Outlook

Considered surgical intervention:

Navigated drilling of holes in human vertebra for high precision placement of pedicle screws



Workflow

1. CT- scan
2. Intraoperative registration
3. Planning of screw placement
4. Verification
5. Drilling of hole
6. Manual screw placement

Registration

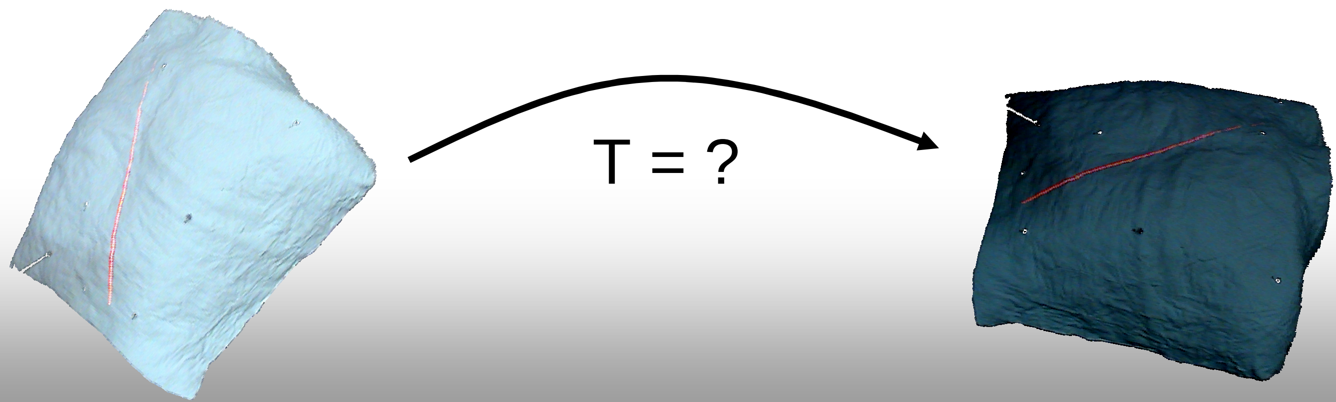
Registration: finding a spatial mapping between two data - sets

Registration methods can be classified according to the

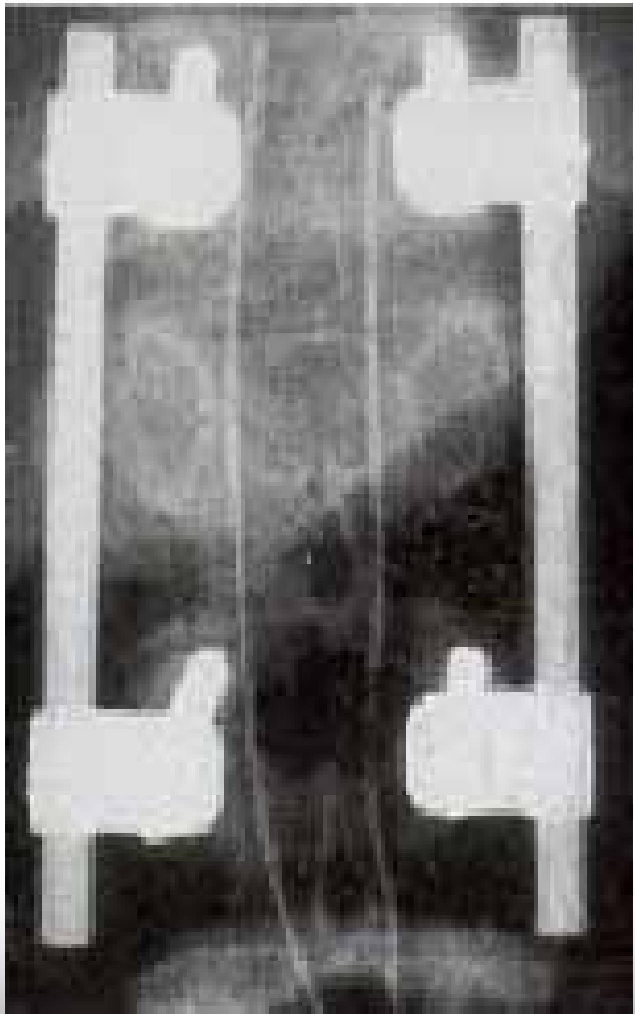
- feature space (landmarks, surfaces, lines, voxels, …)
- search space (transformation, rigid, non-rigid, …)
- search strategy (exhaustive, gradient based, EA, …)
- similarity measure (SSD, mutual information, correlation, …)

In the case considered here:

- points on the vertebra are collected with a tracked pointer
- these points are then matched with the CT – data
- a rigid – transformation with 6 DoFs is used

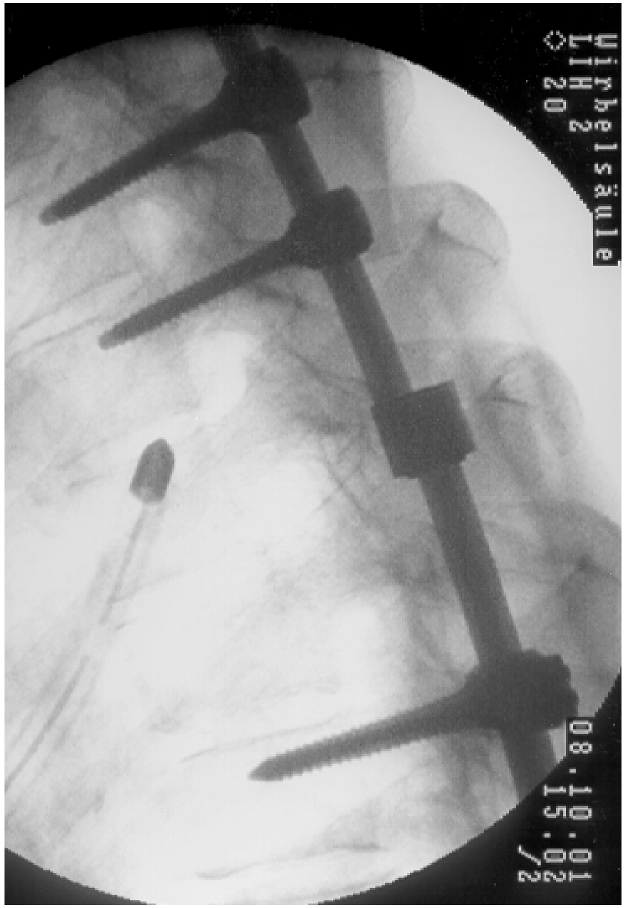


Transpedicular Fixation with Fixateur Interne



Figures: courtesy of Prof. Beisse, BGU Murnau

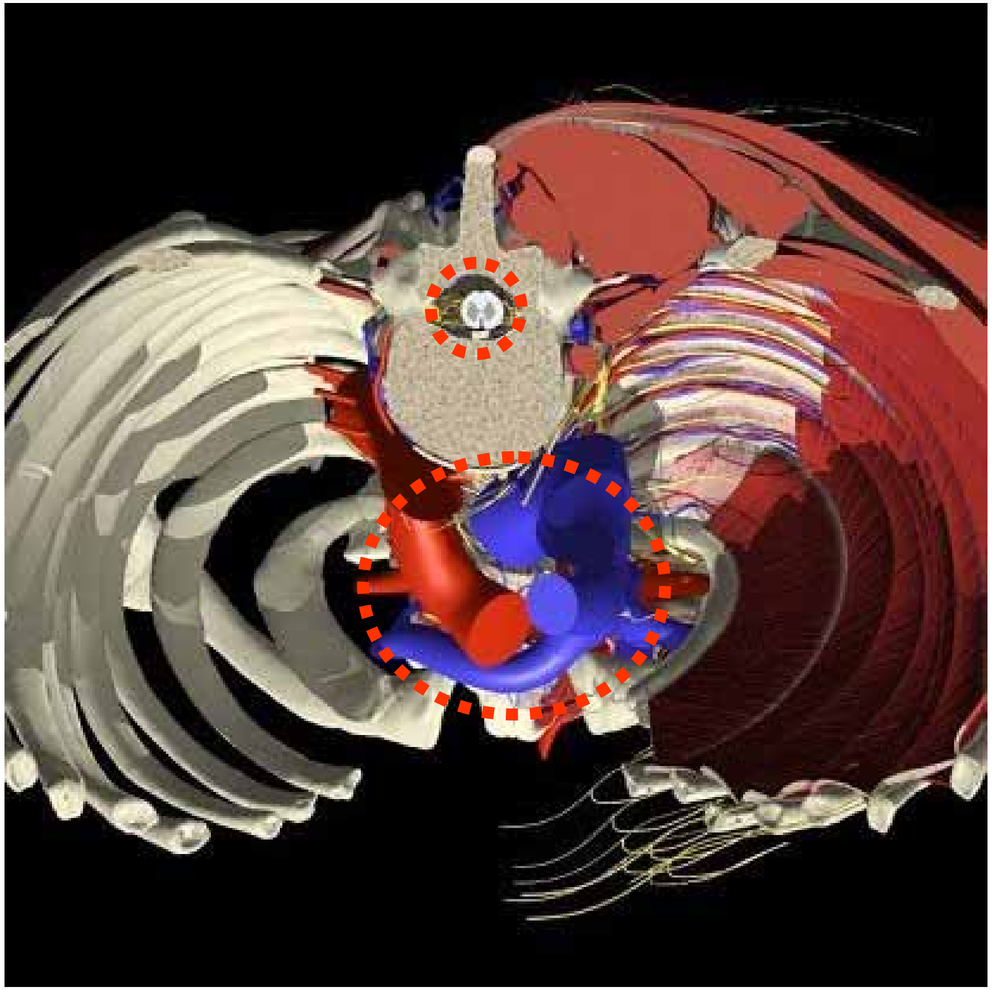
Medical Application

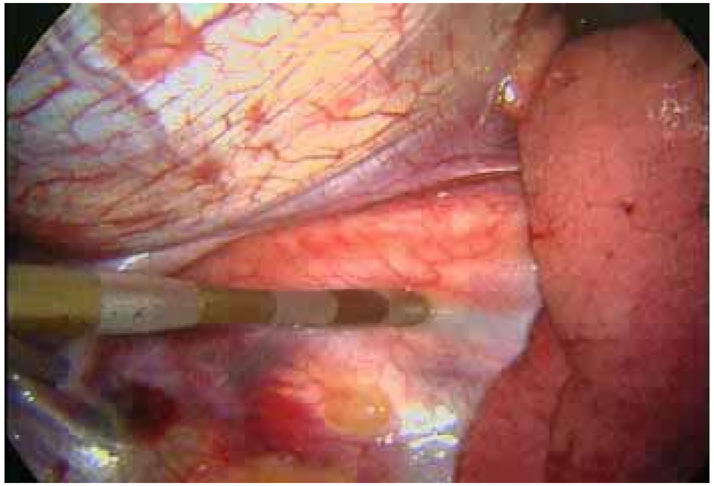


X-ray image of correctly placed pedicle screws

Figures: courtesy of Prof. Beisse, BGU Murnau

Medical Application





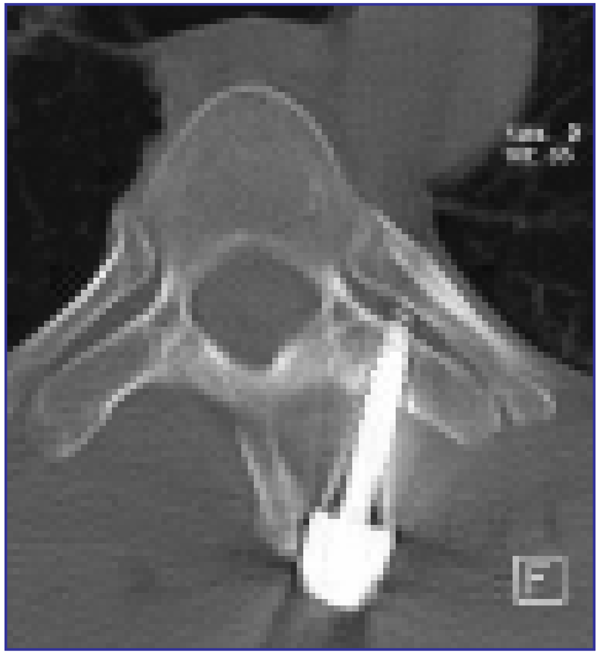
Surgeon‘s view

Delicate structures are close to pedicles

Figures: courtesy of Prof. Beisse, BGU Murnau

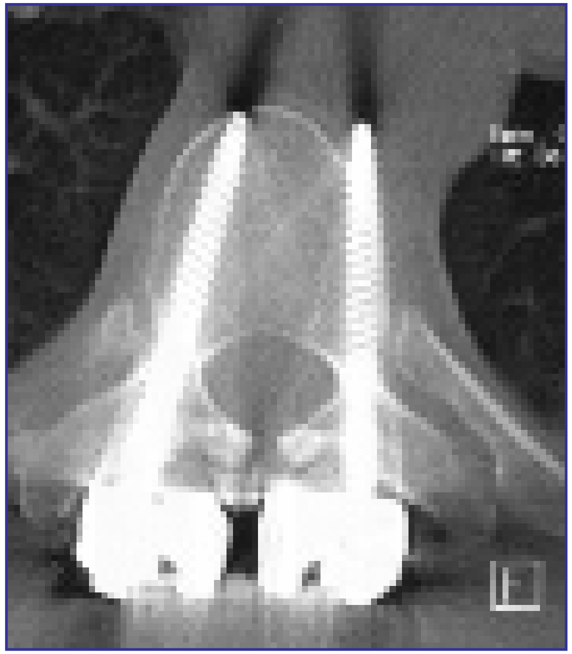
Medical Application

Misplaced screws



thoracic vertebra 5

thoracic vertebra 6



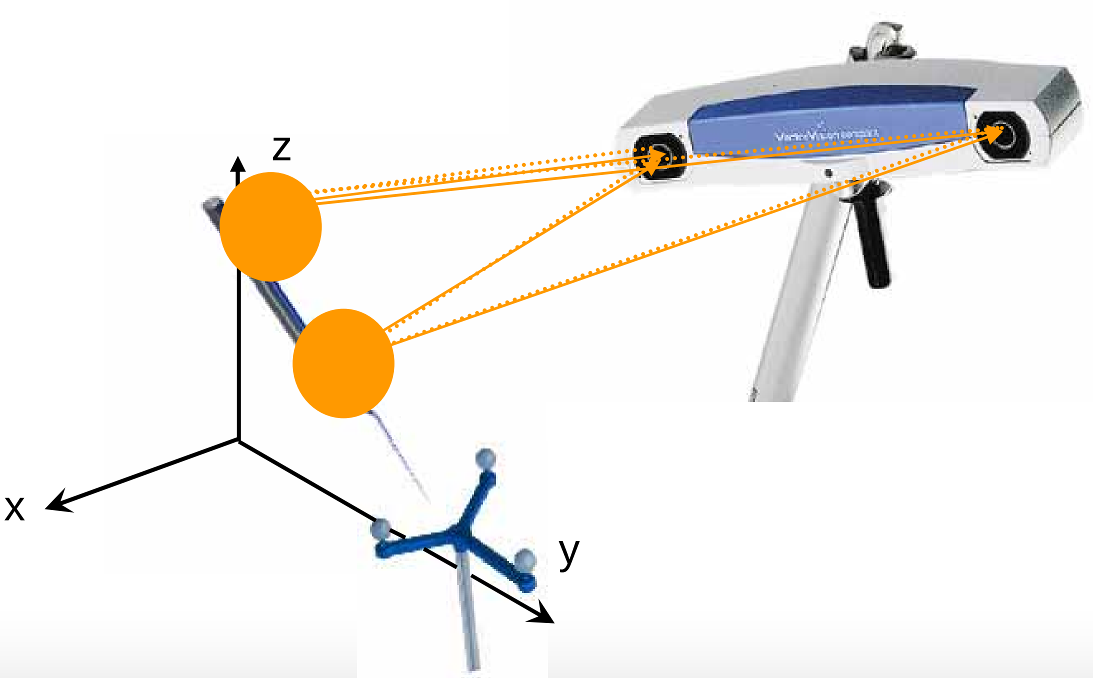
thoracic vertebra 8

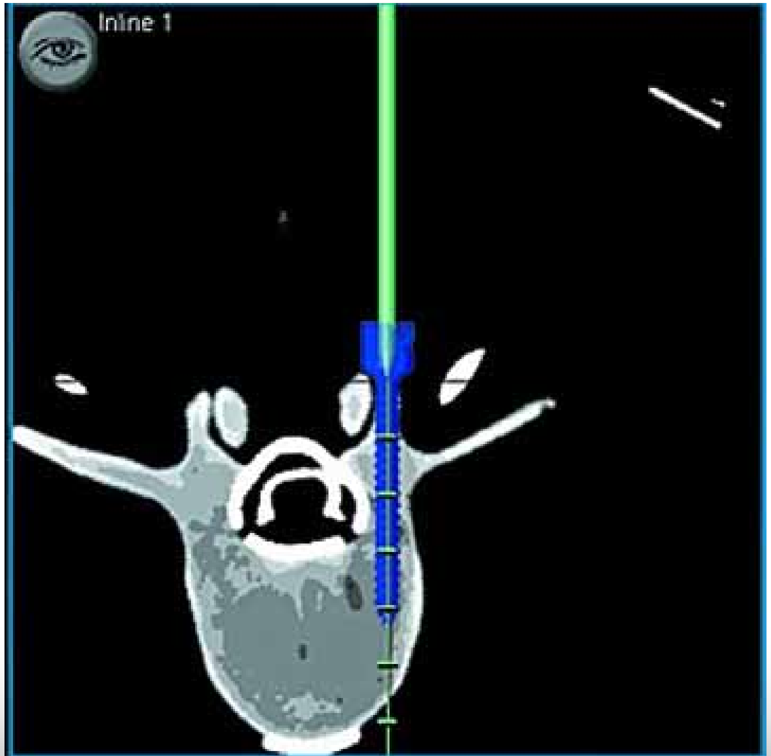
Error rate between: 4.5% - 40% - depending on reference

Figures: courtesy of Prof. Beisse, BGU Murnau

Tracking of passive marker

- Calculation of 3D position by triangulation
- Visualization of surgical instrument in preoperative CT-scan (registration necessary)





Transfer of planning data into the OR becomes possible by navigated instruments

Problems

- Tremor at instrument tip
- Undesired motion of tip due to drilling forces
- Lack of ergonomics
  - Difficult hand-eye-coordination
  - Frequent changes of view direction
  - Frequent new eye accomodation
  - 2D representation of a 3D error

Medical Application

Considered surgical intervention:

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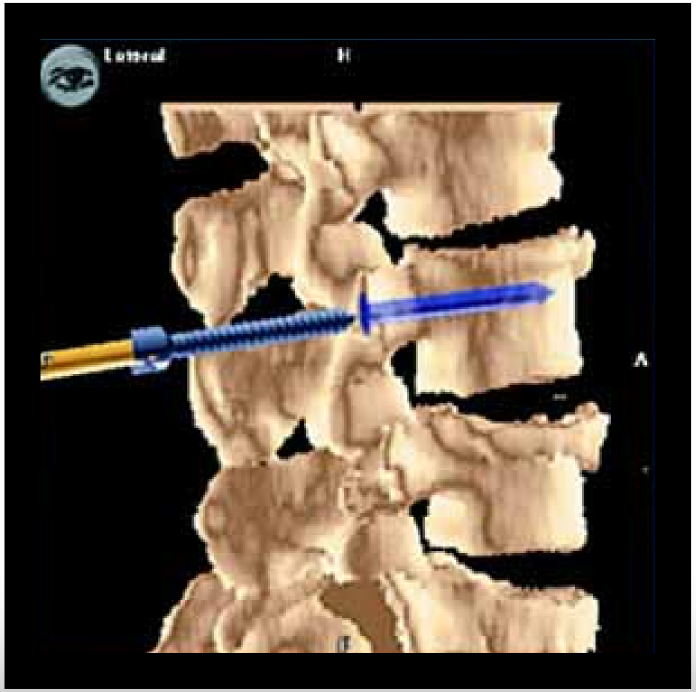

Workflow

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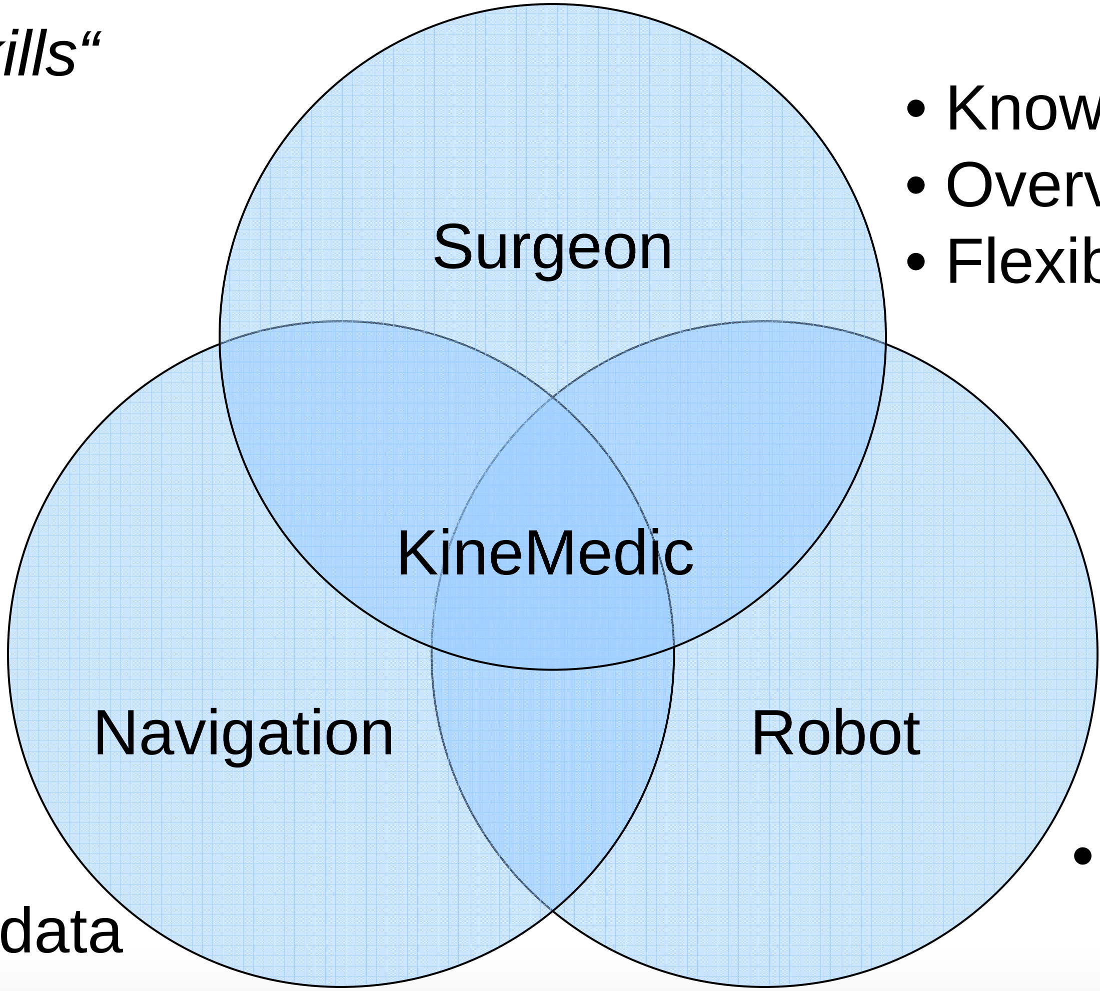
Main idea

„best of skills“

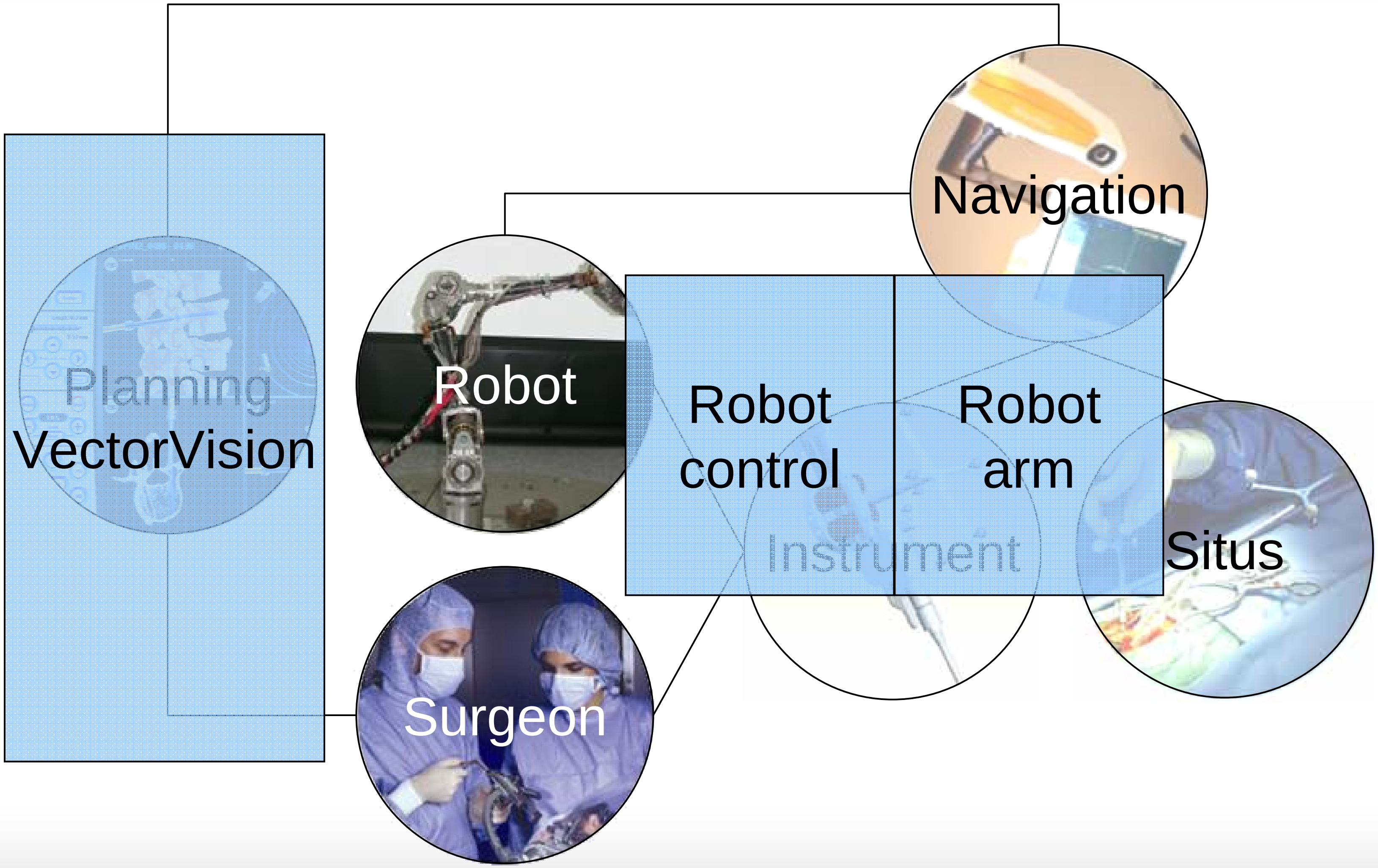


- Know-how
- Overview
- Flexibility

- Manipulation

- Tracking data

System components



Advantages of KineMedic

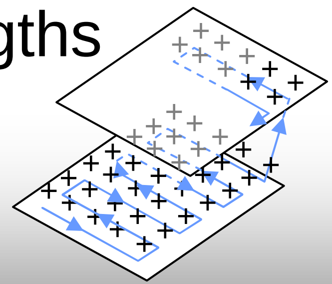
1. Integration in established clinical workflow
2. Closing of the digital gap in the OR
   → Fewer changes of view direction
   → Fewer new eye accomodations
   → Reduced 3D / 2D problems
   → Easier hand-eye-coordination
3. Hands-on-robotics approach (no fully autonomous mode)
   → Intuitive man-machine-interface
   → Surgeon keeps full control of system
4. Easy handling of robot thanks to kinematic redundancy and light-weight construction
5. Gravity compensation
   → Intelligent instrument holder
   → Conversion to manual surgery possible at every time
   → Increased acceptance by surgeons (hopefully ☺)

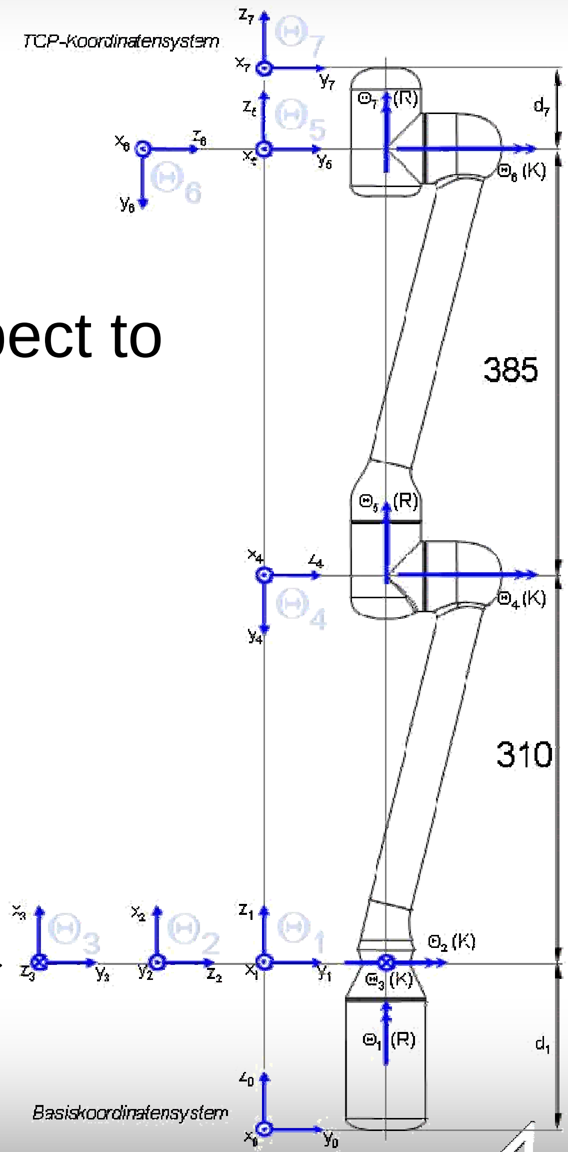
1. Application and concept
2. Design requirements
3. Robot components
4. Summary and Outlook

Design

Kinematic design

- Kinematic redundancy (7 DoFs)
- Analysis of fields of application with respect to workspace and accuracy
- Optimization goal:
  compact design
- Constraints:
  accuracy, manipulability,
  robustness of solution
- Minimization of segment lengths with *Genetic Algorithms*





Design

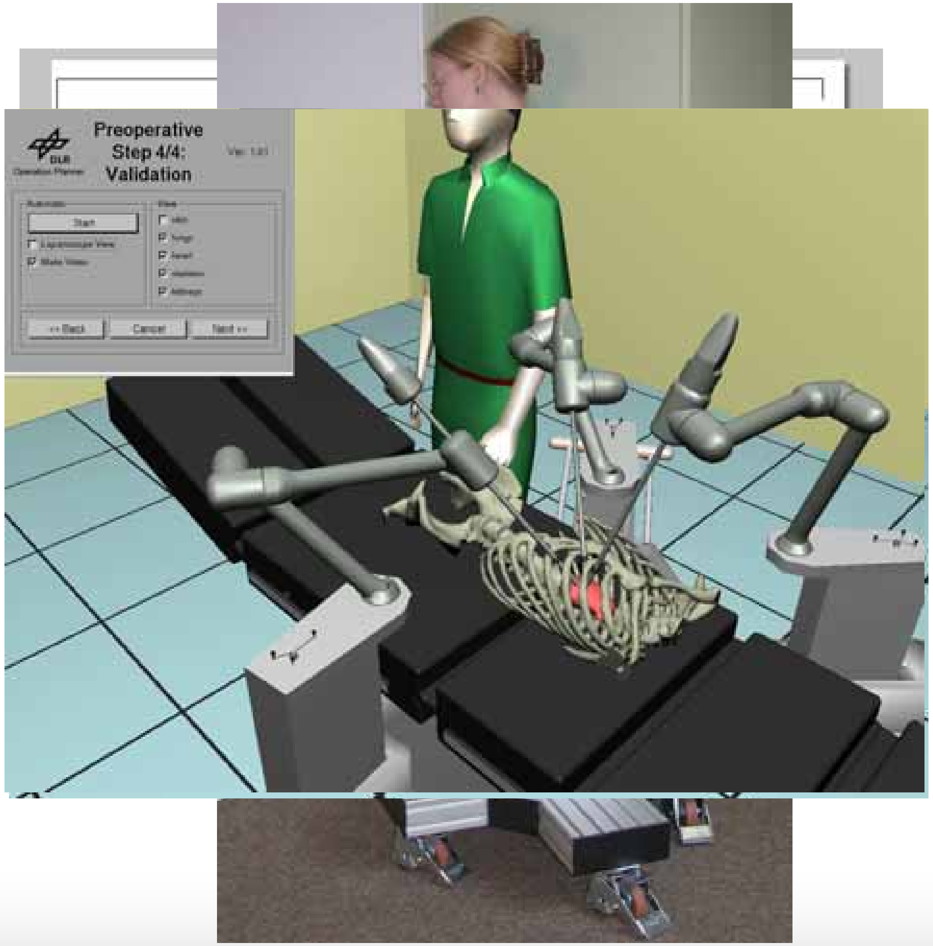
Mounting of the robot

Requirements

- Fast installation of robot
- Easy positioning
- Security

Development steps

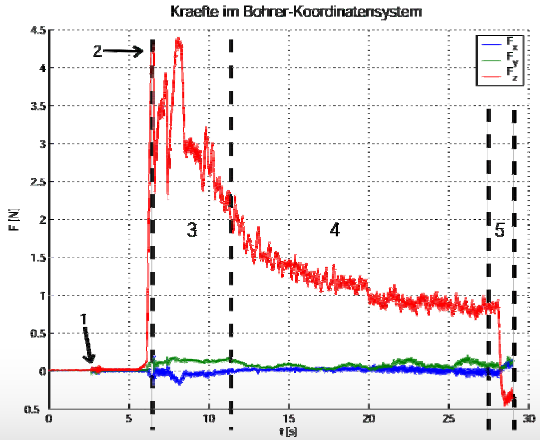
- Simulation environment
- Identification of set-ups
- Modeling and construction of a prototype



Measurement of external forces

Experiments

- Drilling experiments with testing machines
- Drilling experiments with robot



Results

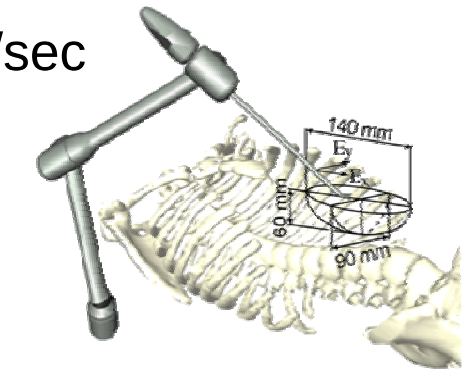
- Cutting and drilling forces
- Selection of appropriate drills and milling cutters

In cooperation with Technical University of Munich

Design

Design parameter for entire system

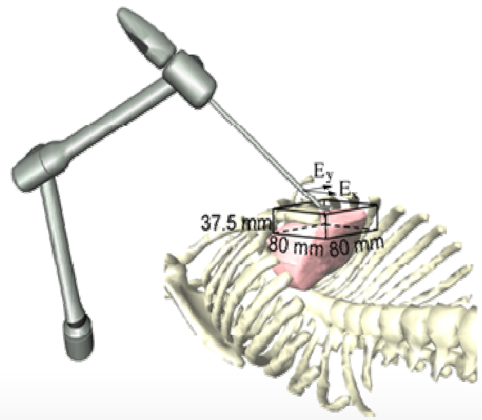
- Maximum forces: F = 30 N
- Guaranteed minimal Cartesian velocity: v = 25 cm/sec
- Work space for MIS: 200 mm x 200 mm x 100 mm
- Accuracy of entire system (robot + navigation): $\Delta x = 1$ mm
- Operation of robot via navigation system
- Semi-autonomous guidance of instrument (robot + surgeon)



Results

Robot for many clinical applications, e.g.:

- Orthopedics
- Minimally invasive surgery (e.g. heart- and visceral surgery)
- Robot for laparoscopy (i.e. camera holder)
- Robot for biopsy



Overview

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3. **Robot components**
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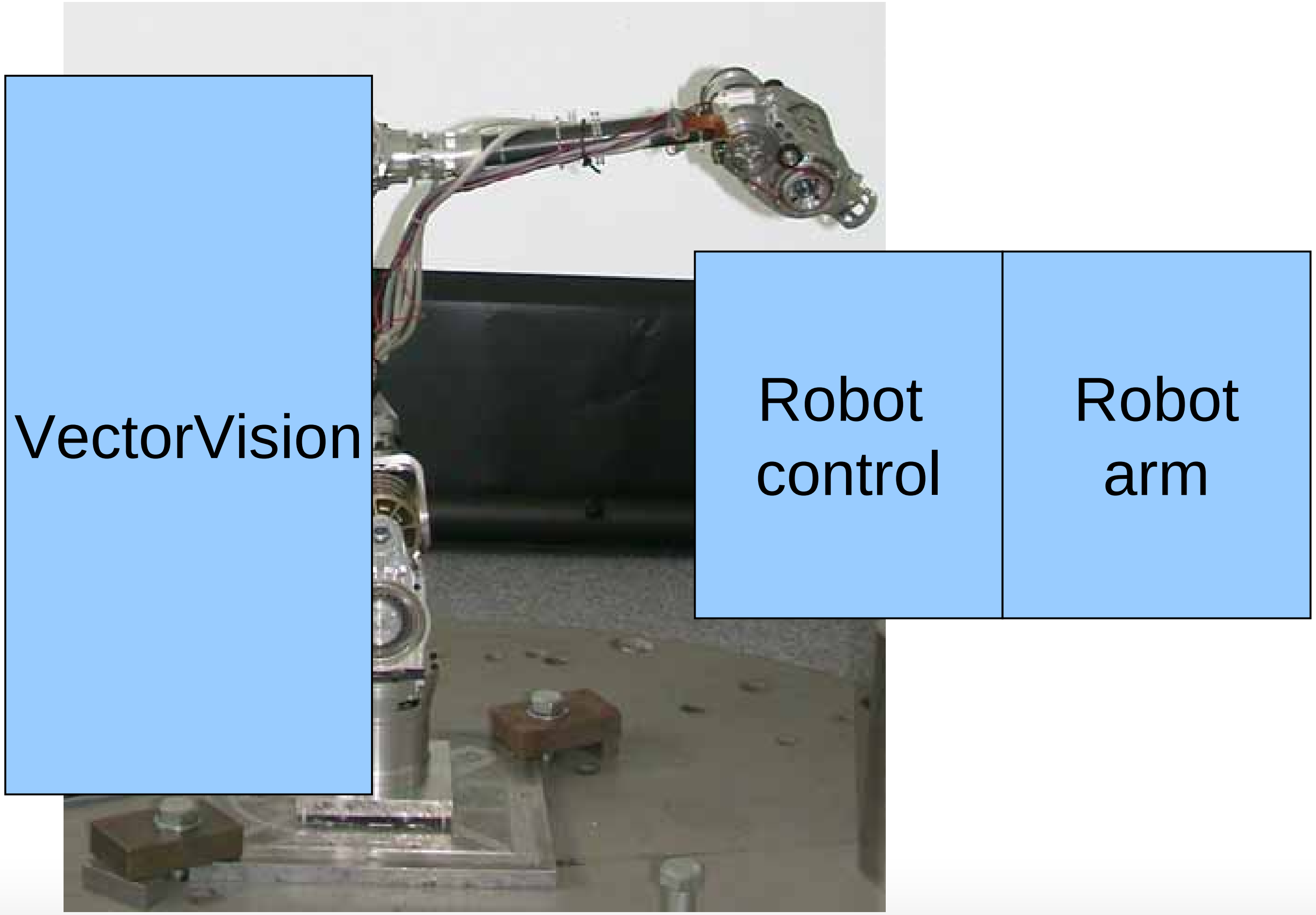
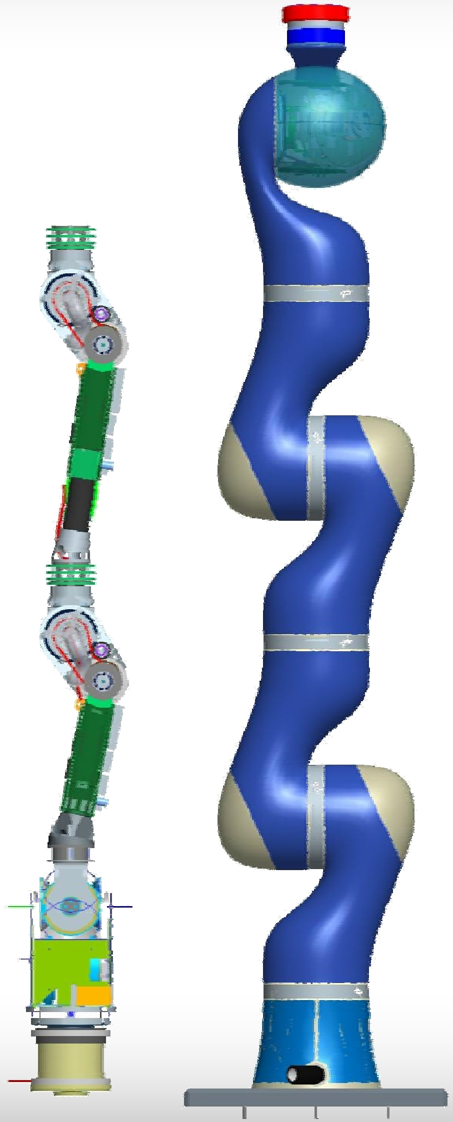
Robot Arm



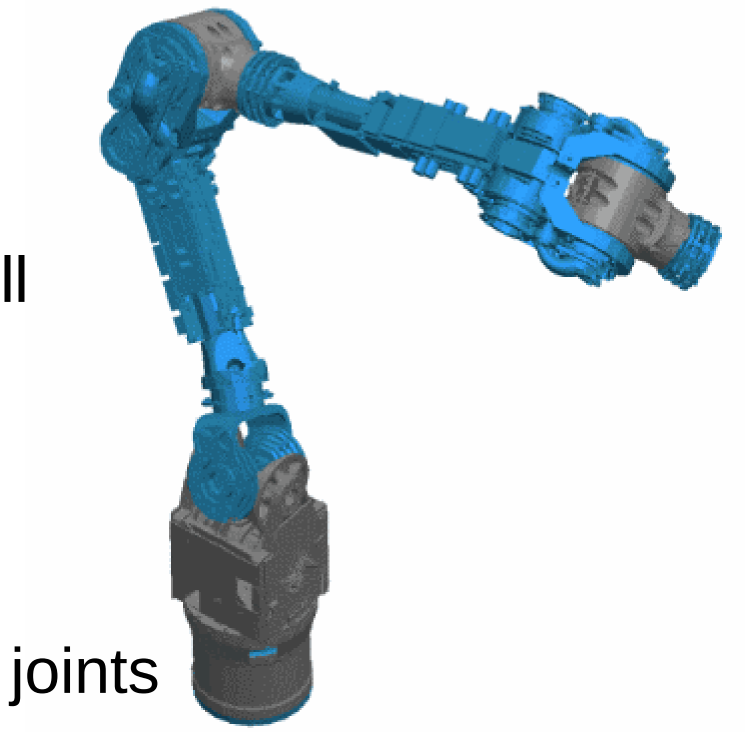
Robot Arm

Goals

- Optimized power consumption
- Precise and sensitive control
- Easy to maintain



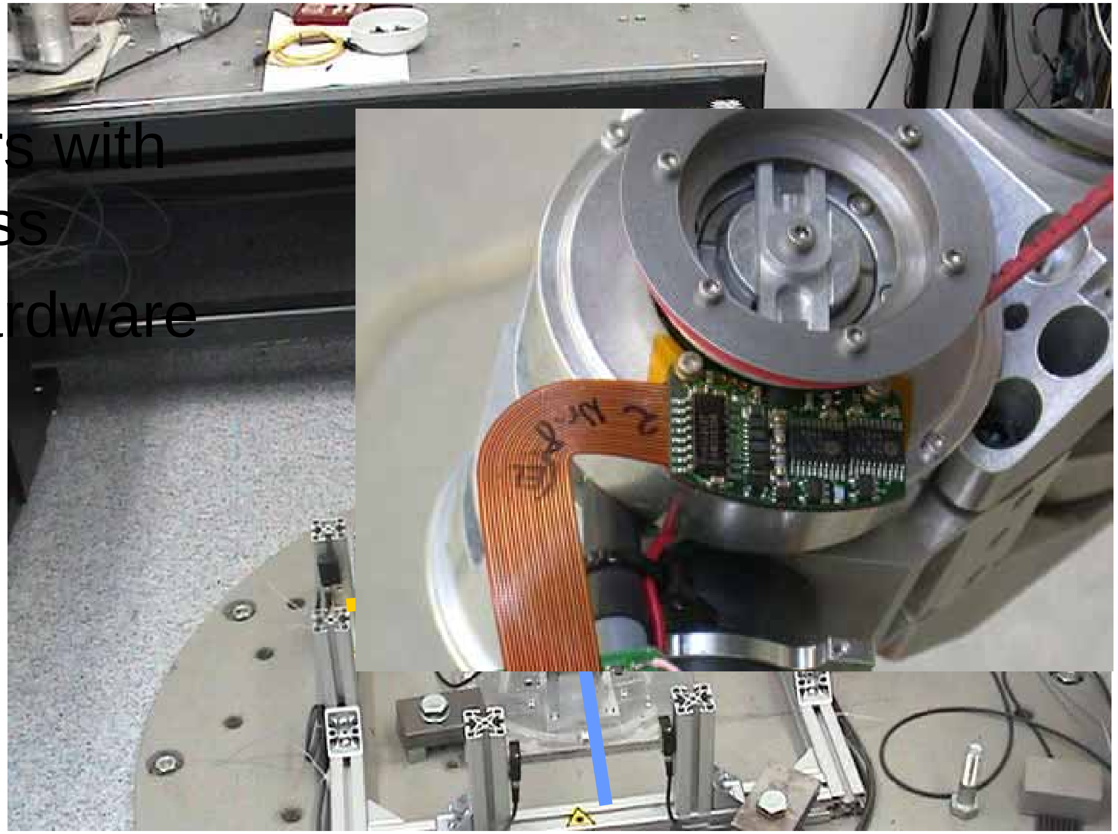
Design demands



- Seven axes:
  roll/pitch/pitch – pitch/roll – pitch/roll
- Optimized link lengths
- Slender design
- Asymmetric range of motion of the joints
- Low weight < 10kg

- Optimized power consumption

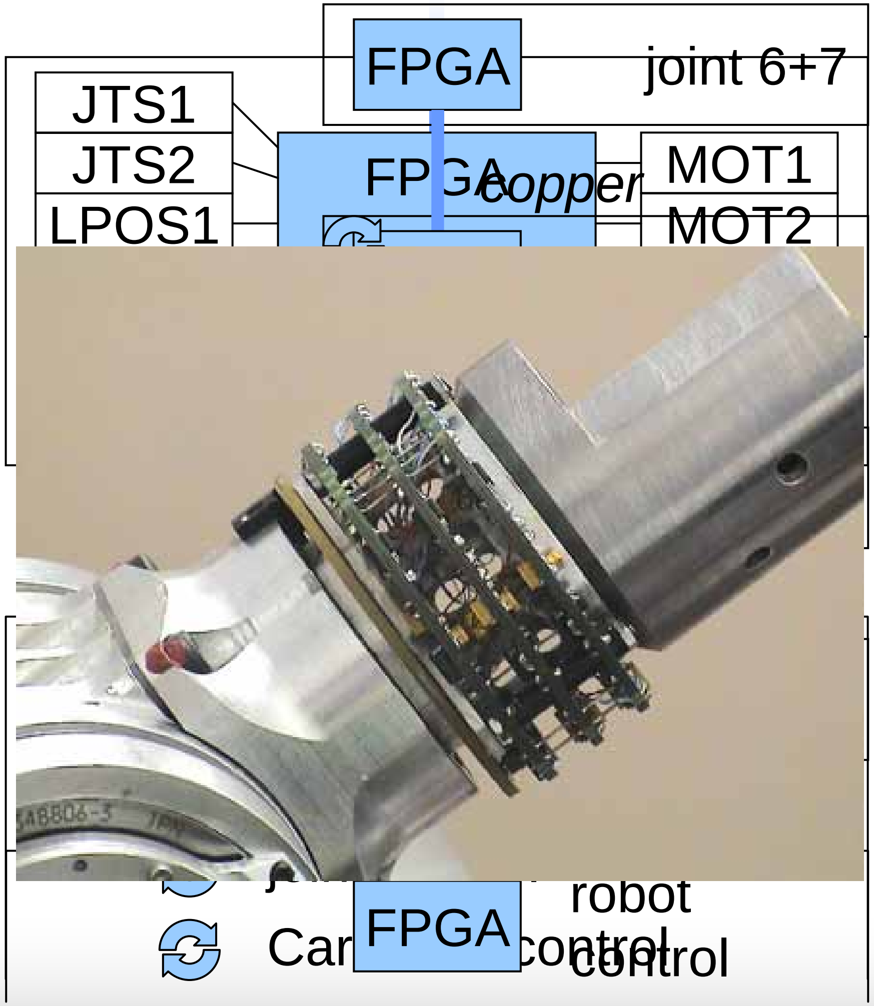
- Specialized motors with reduced power loss
- Programmable hardware



Robot Arm

Precise and sensitive control

- Broadband communication bus between joint units (1 GBit/s)
- Centralized joint control
- Powerful sensors



Easy to maintain

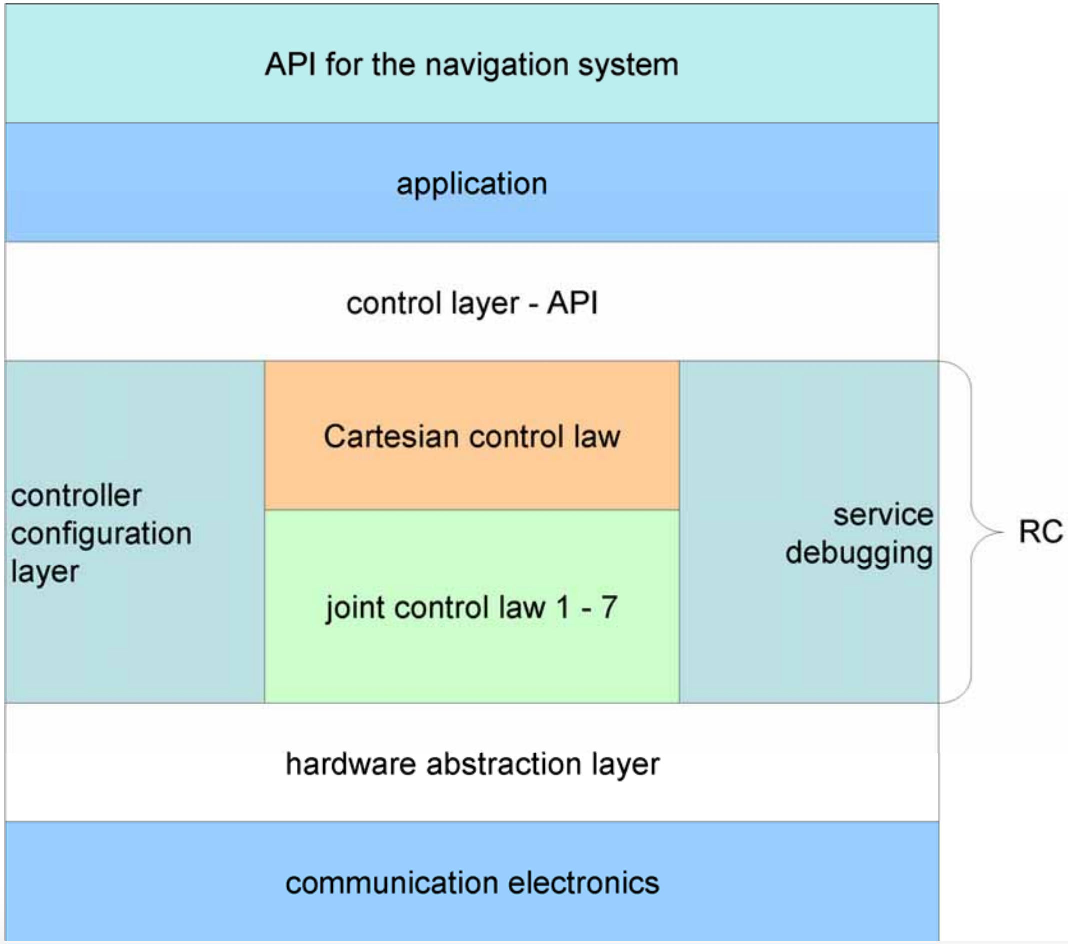
- Similar/identical parts
- Modularity

motor	2 types
break	2 types
motor position sensor	1 type
JTS – circuit board	1 type
gears	2 type

VectorVision

Demands

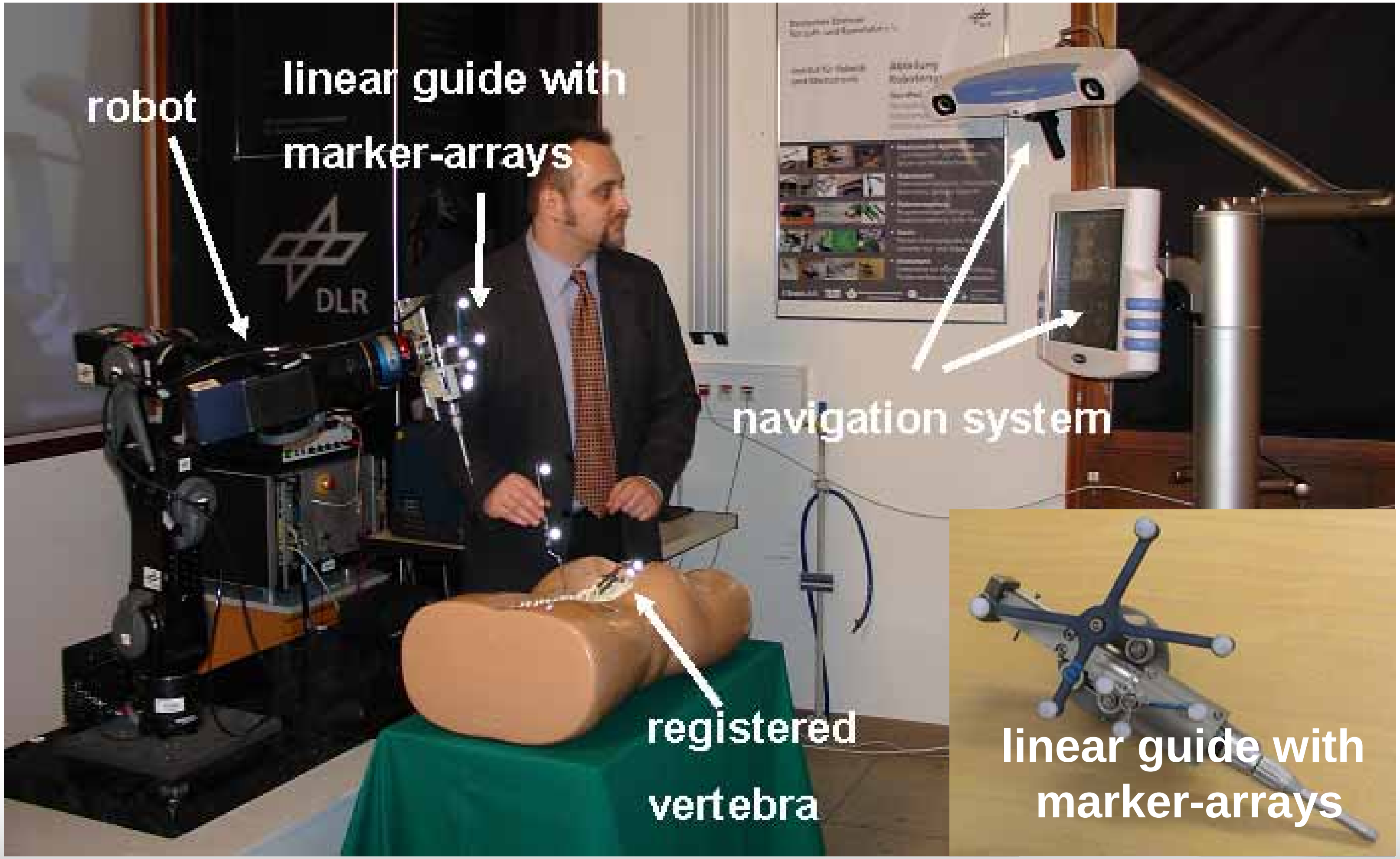
- Communication with robot arm
- Joint control
- Cartesian control
- Logic flow control
- Interface to navigation system
- „Black box“ character for end-user



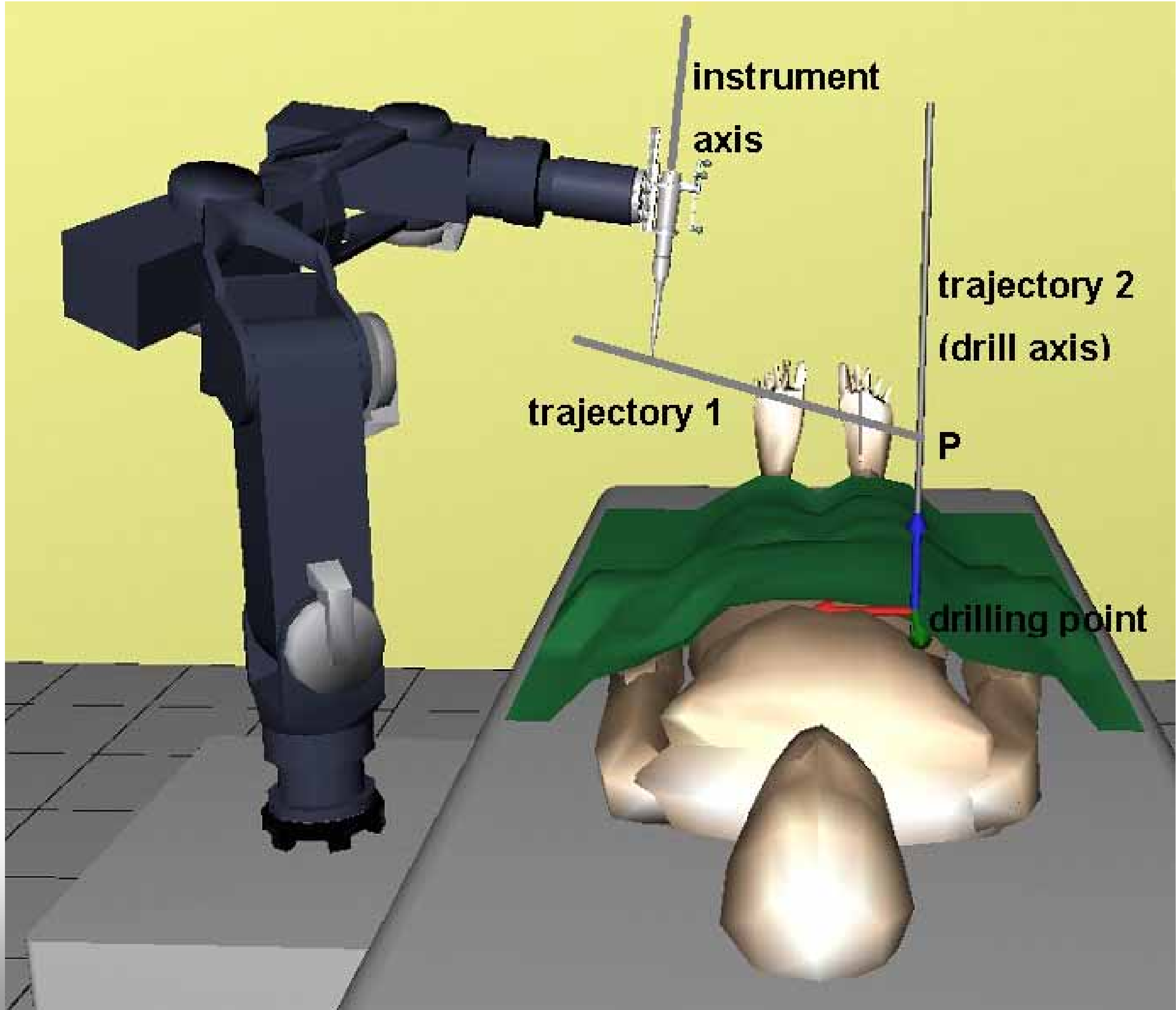
Cartesian impedance control enables

- „soft robotics“
- programmable stiffness
- sensitive and intuitive man-machine-interfaces
- implementation of virtual walls, virtual constraints (e.g. for peg-in-hole), etc.

Experimental set-up with DLR leight-weight robot



Workflow –Logic Flow Control

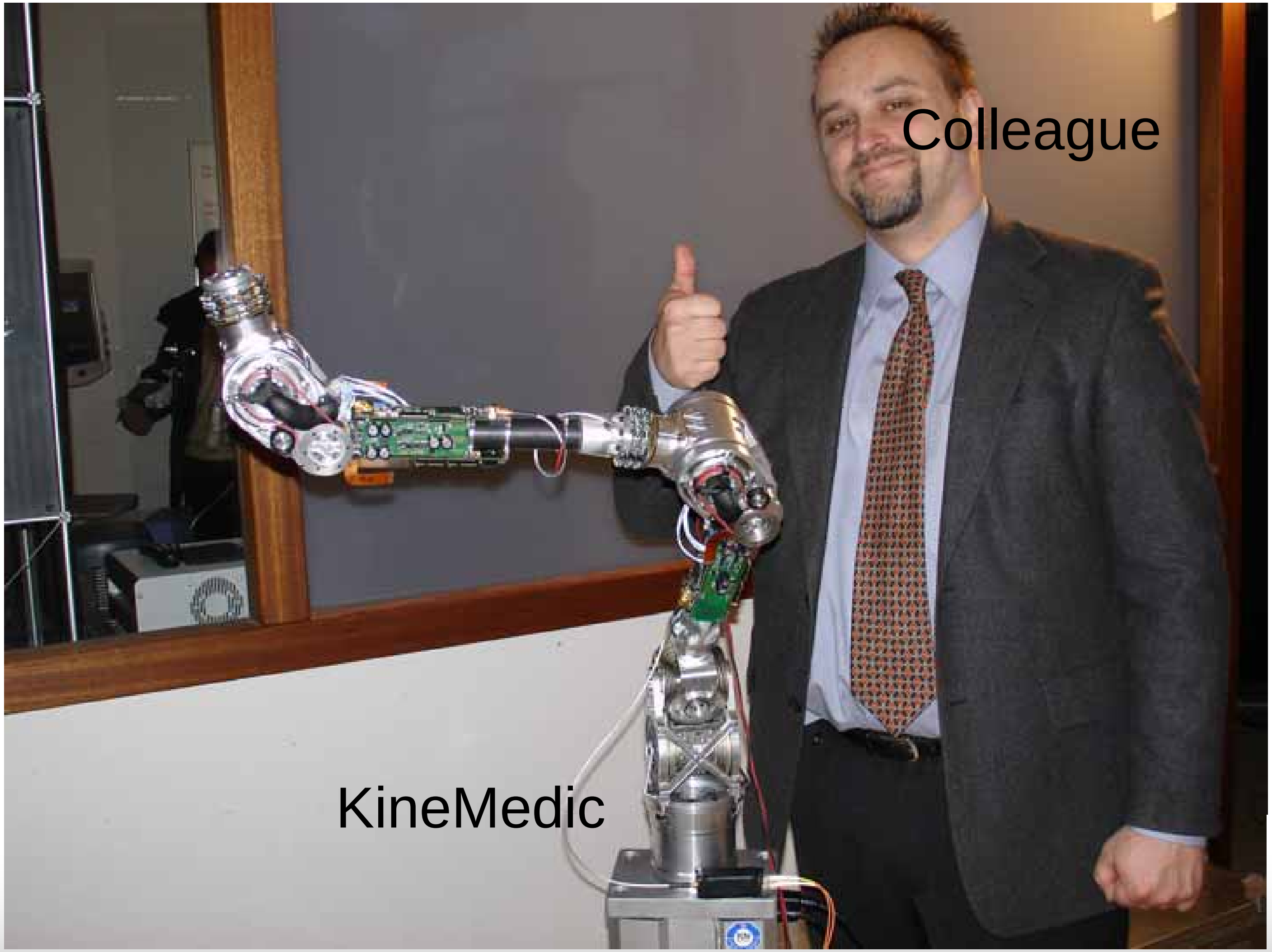


Robot Control

Workflow

- Registration of patient and robot
- Planning of screw placement
- Positioning of robotic arm
- Guidance of instrument to drill hole (hands-on-robotics)
- Manual drilling of hole with visualization of depth
- Secure removal of drill

KineMedic Completed



Robot – First Trajectory

Video

Overview

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Summary

KineMedic, a new robot for surgical applications was presented:

- kinematic redundancy
- torque controlled
- light-weight

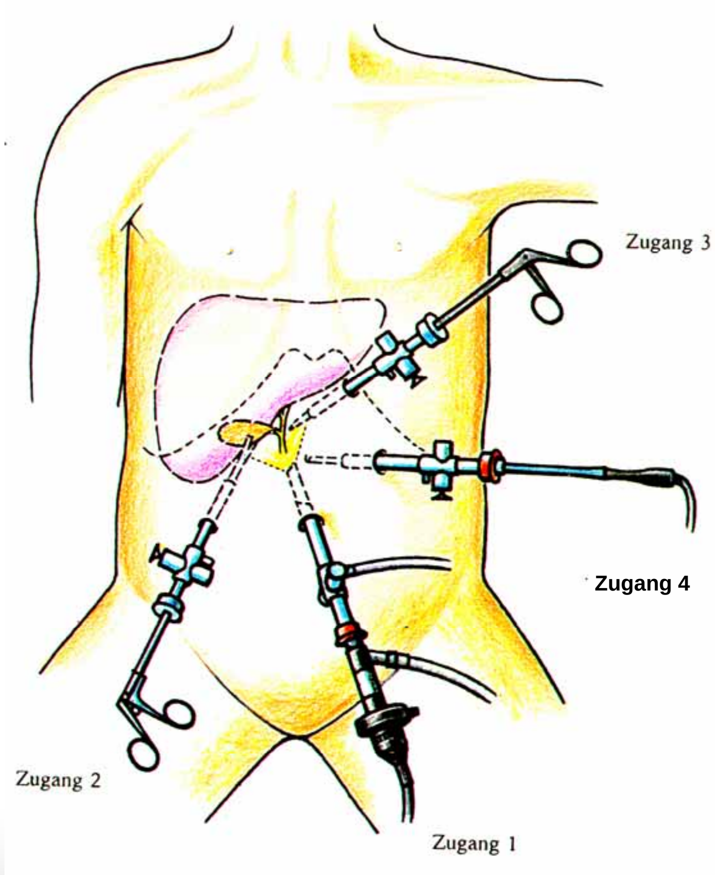
Advantages of the proposed system:

- Integration in established clinical workflow
- Closing of information gap in the OR
- „Hands-on-Robotics“ (no fully autonomous mode)
- Robot is gravity compensated
- Increased acceptance by surgeons

Goal:

- Further development of the robot together with BrainLAB and KUKA towards a serial product

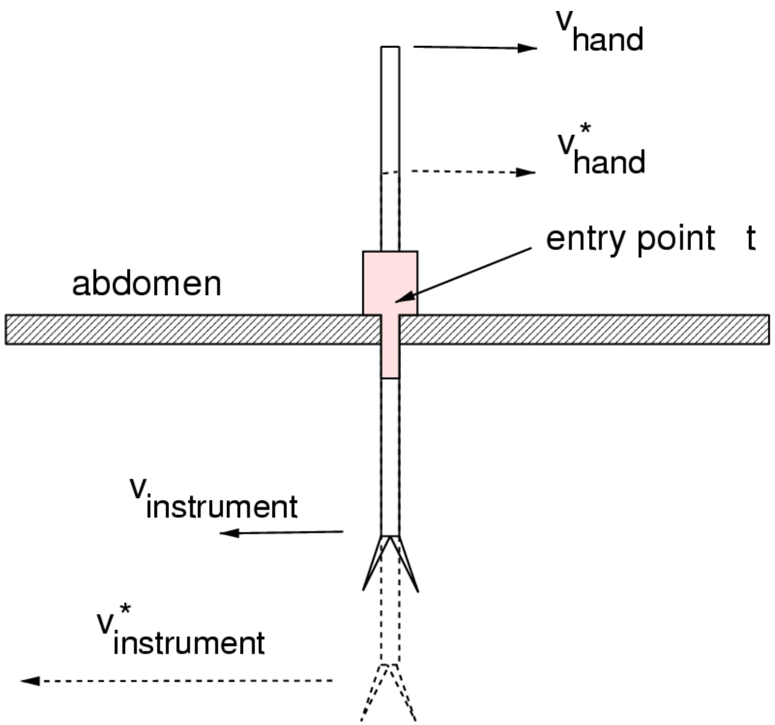
Manual minimally invasive surgery



The surgeon works

- with long instruments and
- cumbersome movements
- through small incisions
- and has only the laparoscope image as visual feedback

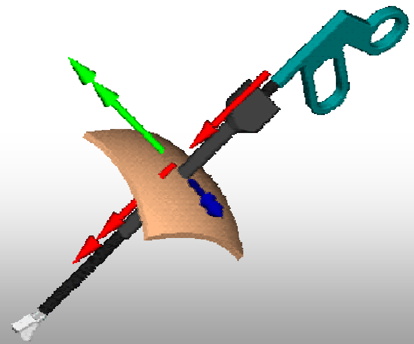
Telepresece helps to overcome barriers



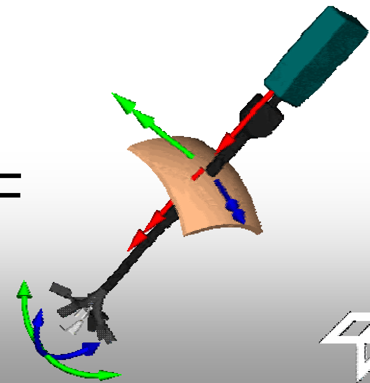
Barrier “patient‘s skin” leads to:

- Reverse hand motion (chop-stick effect)
- Scaling of velocities
- Loss of two degrees of freedom
- Reduced kinesthetic feedback
- Loss of tactile feedback
- Reduced sight

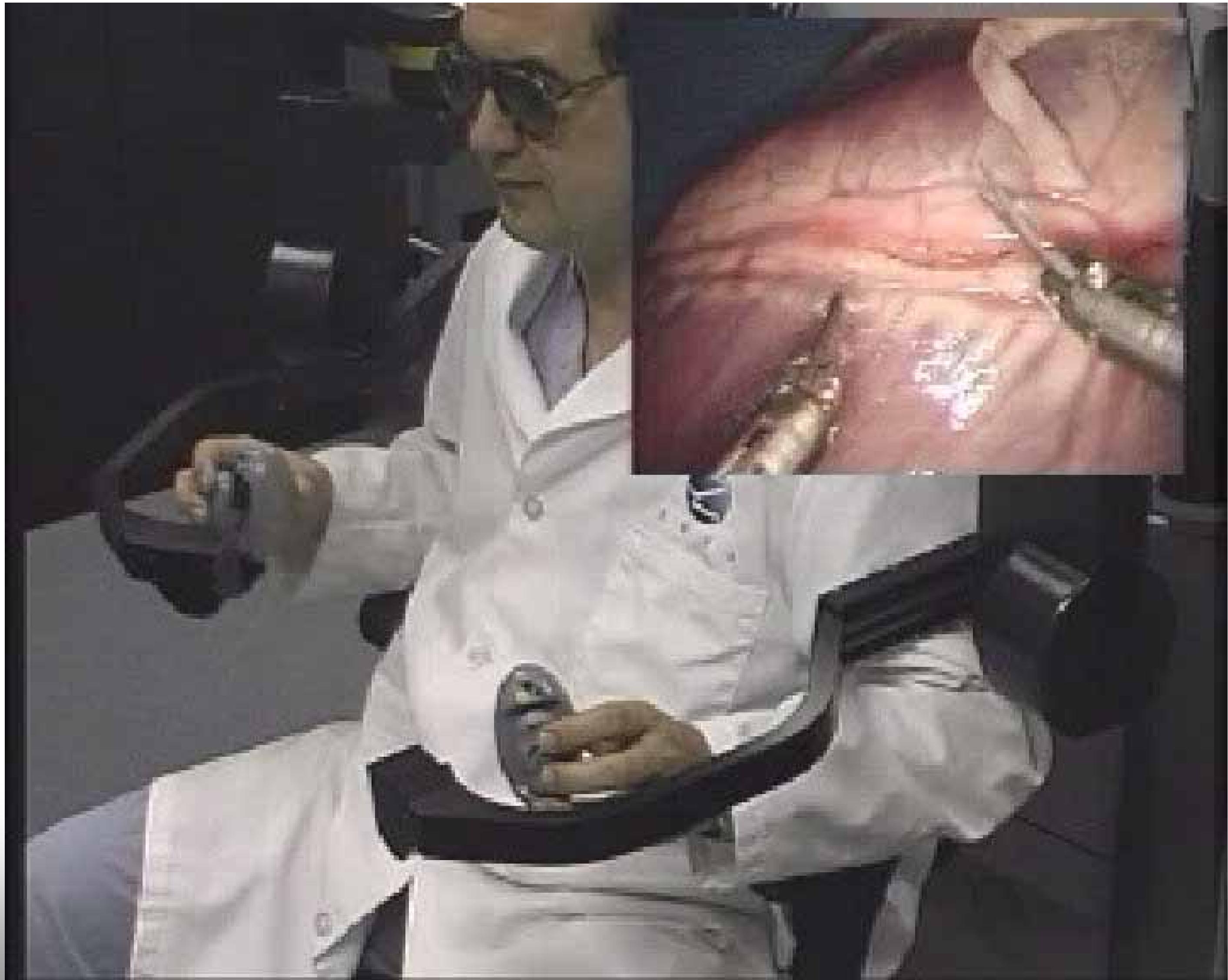
Manual: 4 DoF



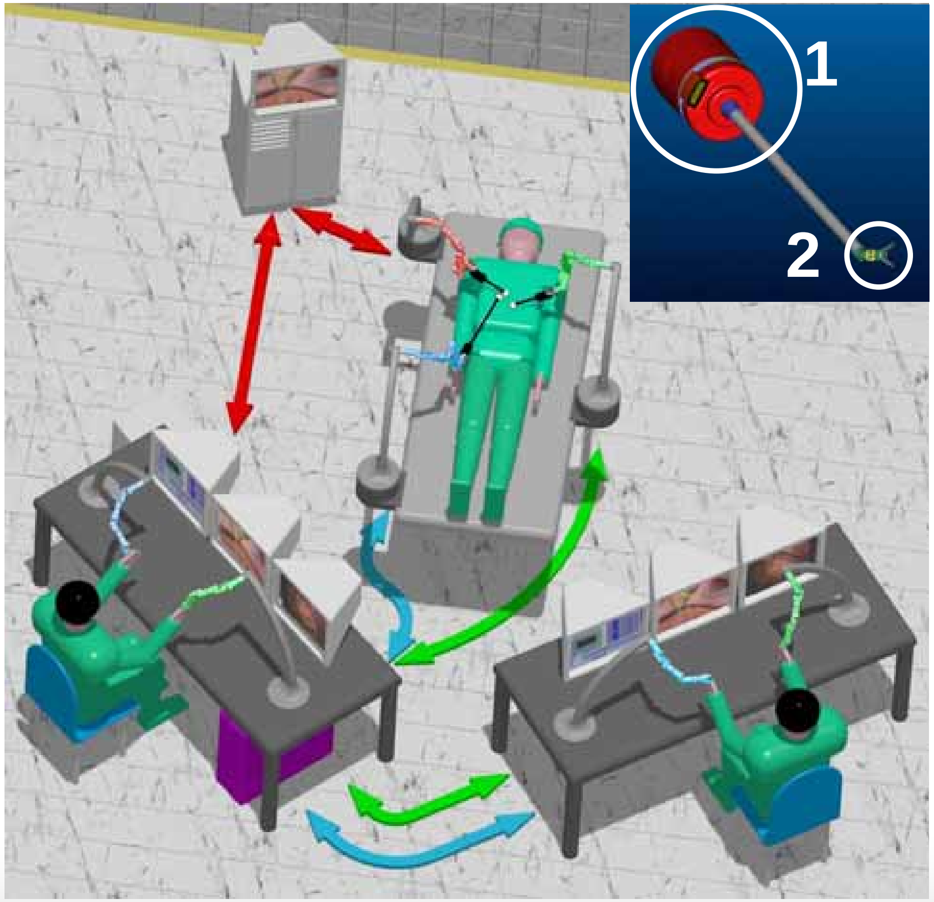
Robot: 6 DoF



Early System: Computer Motion – Zeus



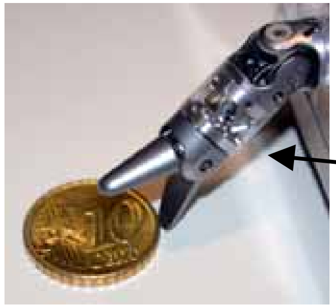
Robotic Surgery – The DLR-Vision

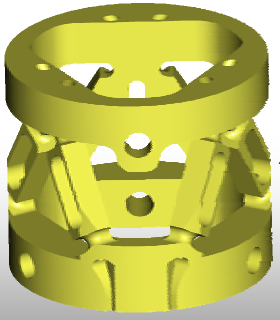


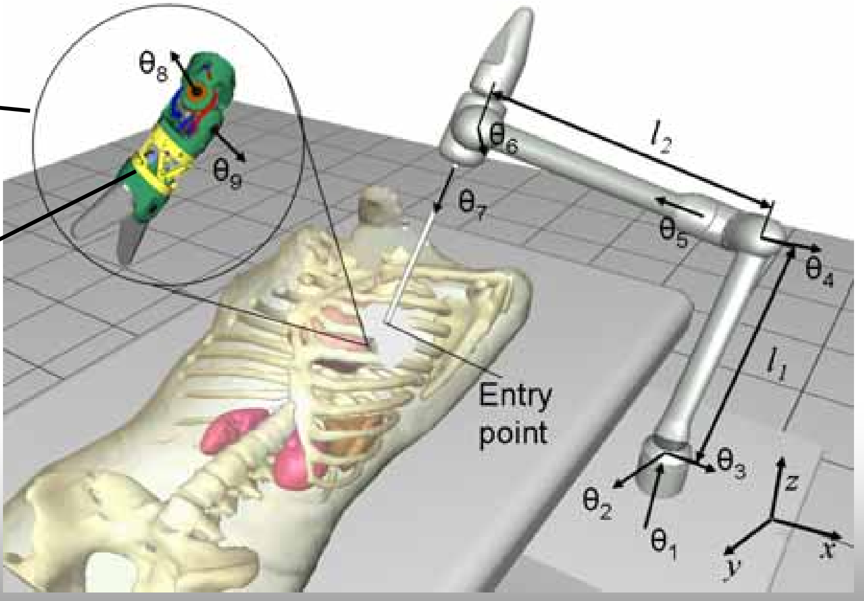
Telepresence helps to overcome barrier "patient's skin"

KineMedic can also be used for telepresence MIS

- Full manipulability at distal end (inside patient)
  → 2 additional degrees of freedom at instrument tip
- Measurement of contact and grasping forces
  → miniaturized force/torque sensor (Ø 10 mm, sterilizable)







Entire System

Surgical workflow

- CT – scan
- Segmentation
- Patient specific, optimal, and automatic planning of
  - robot and
  - port

  pose
- Verification
- Registration of patient
- Transfer of planning data into OR

Thanks to

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  - Bavarian Competence Center of Mechatronics
  - German Research Foundation
  - BrainLAB AG

If you are interested in

- an internship
- a diploma/bachelor/master thesis
- a stay/research period

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