



Novel Low-Cost Sensors for Robotic Machining

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Advances in robot machining

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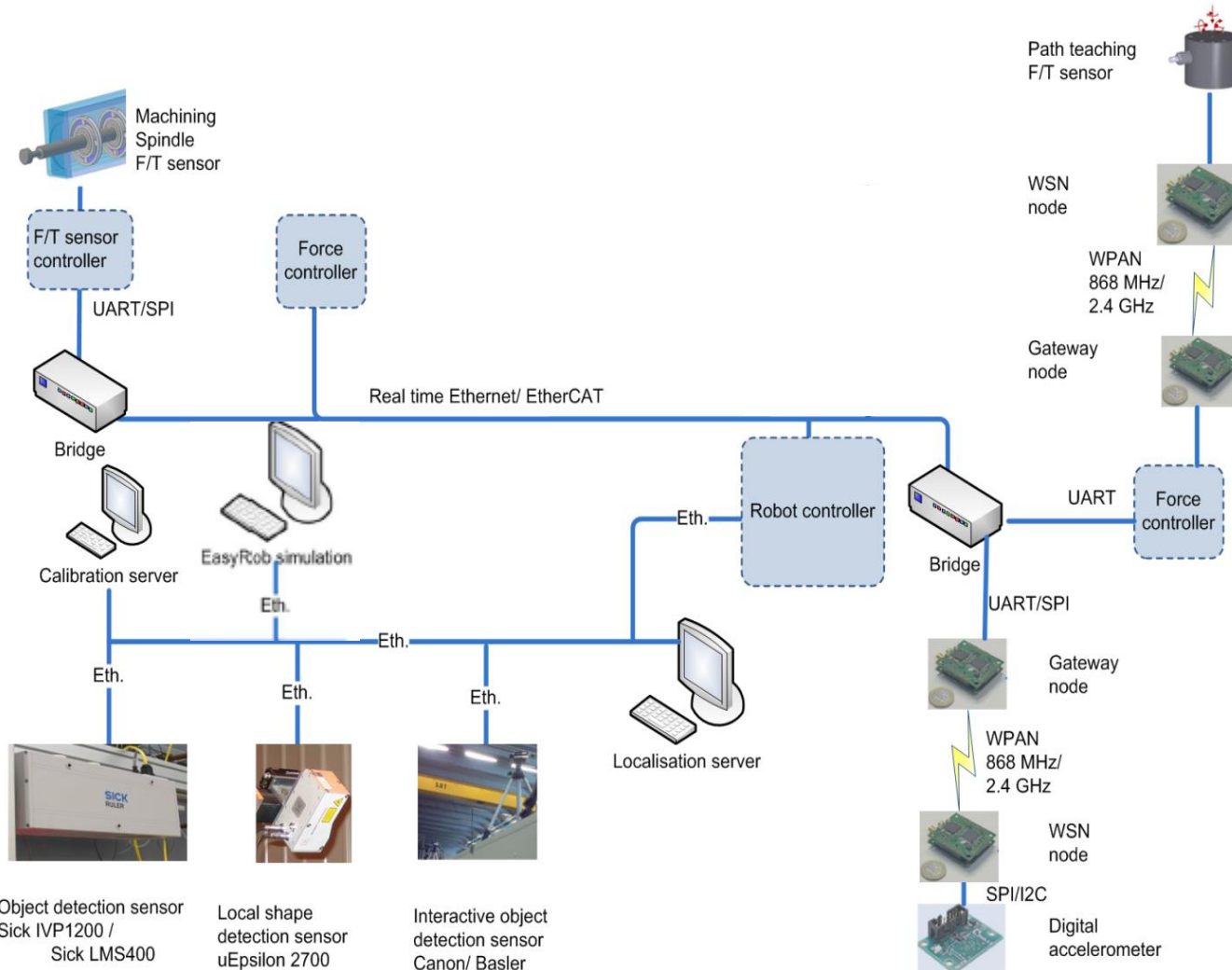
CONTENT

- Sensor operations in flexible robotic machining
- Sensor system architecture for robot machining
- Force/torque sensor module for machining control
- Wireless force/torque sensor module for teaching machining paths
- Object detection and localisation procedure
- Automatic object detection and localizing: Global localization
- Hand Eye Calibration (Global localization)
- Interactive object detection and localization
- Hand Eye Calibration (interactive global localization)
- Automated object detection and localizing: Local localization
- Hand Eye Calibration (Local localization)
- Conclusions

Sensory operations in flexible robotic machining

- **Machining task execution:** robot with a tool and a force/torque sensor ->
tool paths following the local object shape, 80 – 1000 Hz, +/- 1-2 N
- **Teaching machining paths by showing:** robot with a tool and a force/torque sensor & hybrid force/position control ->
tool paths following the local object shape, 10 – 100 Hz, +/- 1-2 N
- **Interactive object detection and localization:** simplified optical sensors to detect objects and parts of object; tags on objects, triggered structured light ->
*Global-> local object shape detection and localization, 1 Hz, +/- 1-2 mm
->0.1-0.2 mm*
- **Automatic object detection and localization:** automatic optical sensors to detect objects and parts of objects ->
*Global->local object shape detection and localization, 1 Hz, +/- 2-3 mm
->0.1-0.2 mm*

Sensory system architecture for robot machining



Hard real-time

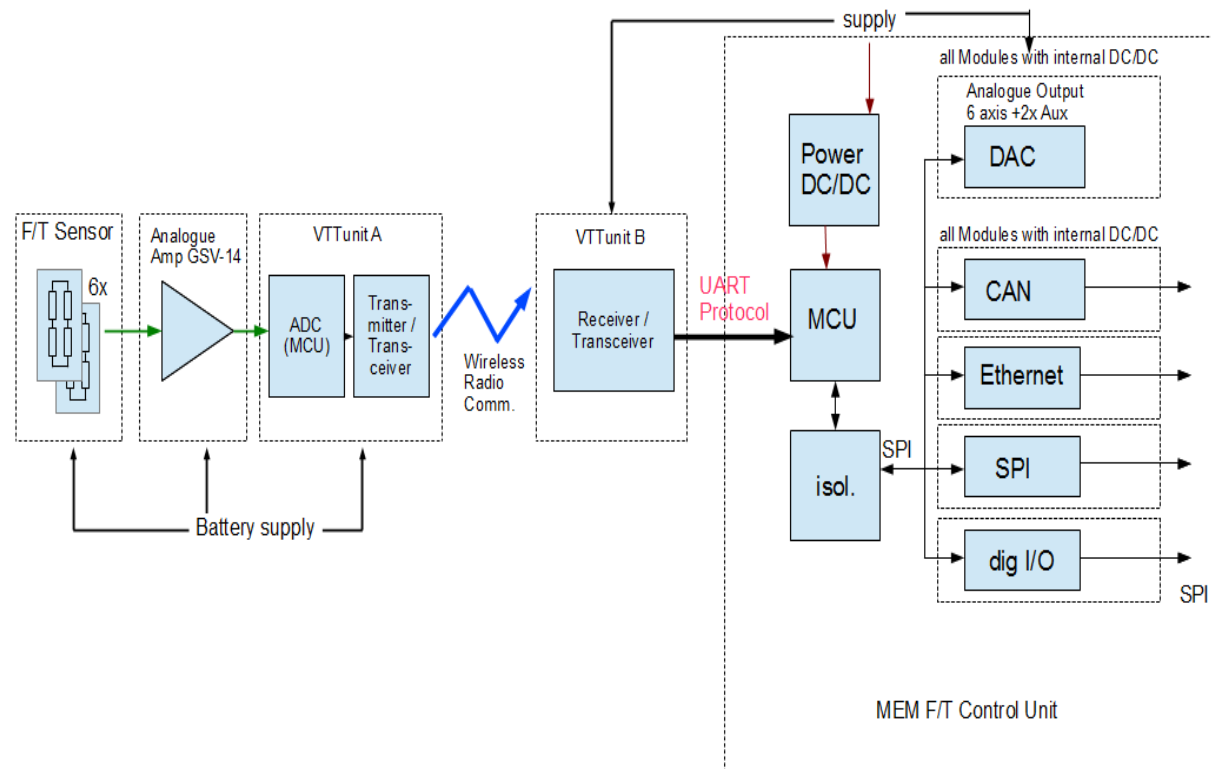
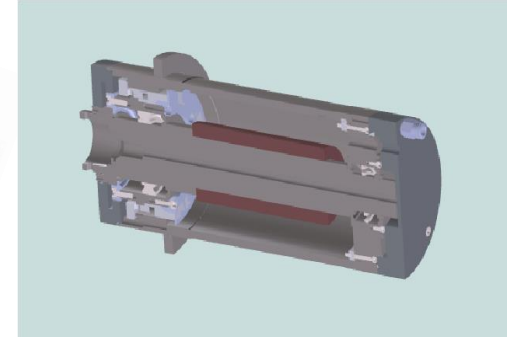
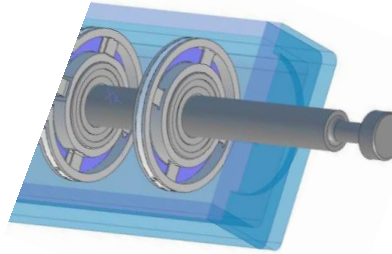
- RT Ethernet/ Field bus
- F/T sensors
- cond. monitoring sensors

Soft real-time

- Ethernet TCP/IP
- Laser scanners
- cameras
- on-line simulation tool
- calibration servers

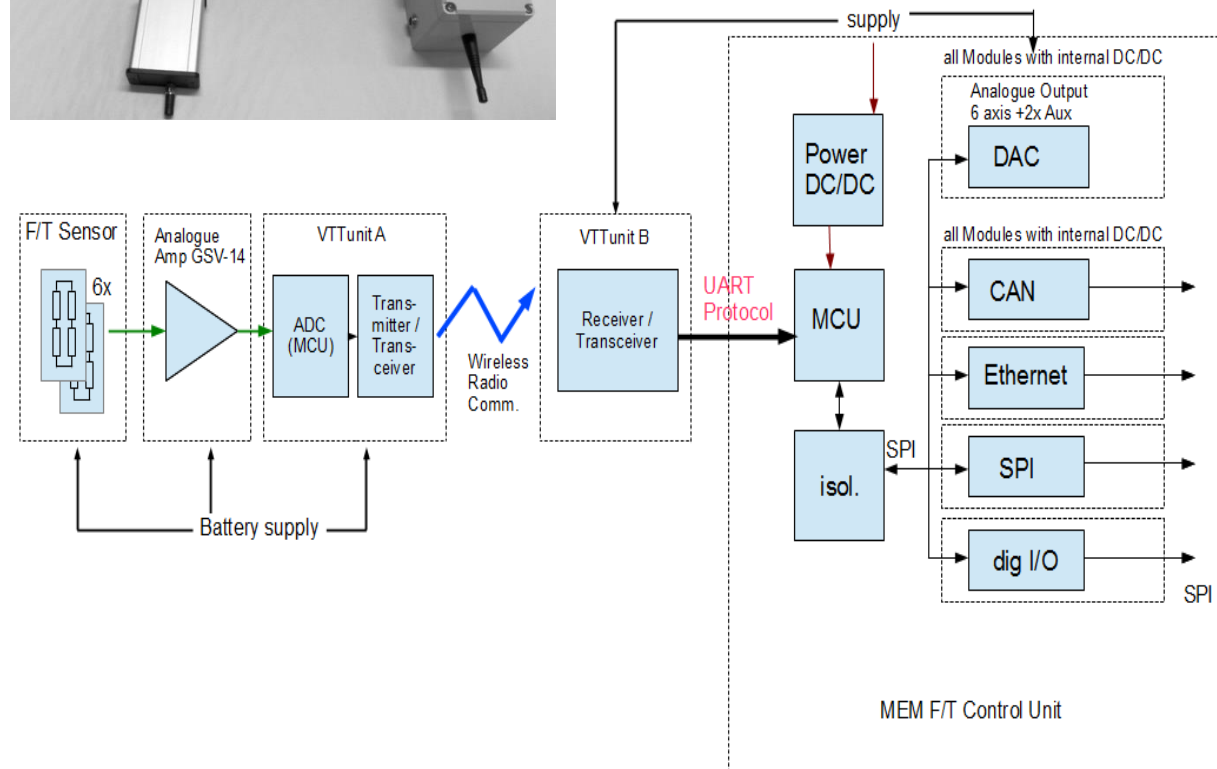
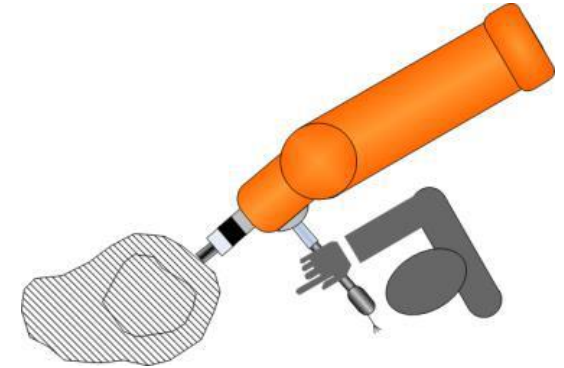
Force/torque sensor module for machining control

- Bearing mounted force sensors for compliant motion control in machining
- MEM architecture:
 - Strain gauges
 - 200 N, 5Nm
 - AD: 16 bit, 20 kHz sampling, 2 kHz output
 - Micro controller
 - system of preloaded bearings is inserted in the sensor
 - Option: 2.4 GHz radio by VTT Node/Little node



Wireless force/torque sensor module for teaching machining paths

- Handle with dead man's switch + F/T sensor
- F/T sensor: ME-Meßsysteme GmbH K6D40, 200 N, 5Nm
- Wireless sensor node
 - Signals amplifiers (GSV-14)
 - AD-converter unit (ADS1278)
 - VTT's wireless unit (VTT Little-node ARM Cortex M0 based radio controller)
 - Batteries
- Gateway unit
 - VTT's wireless unit (VTT Little-node ARM Cortex M0 based radio controller)
- F/T control unit.

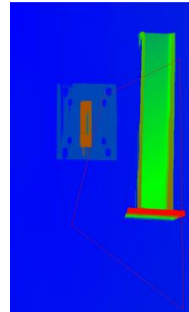


Object detection and localization procedure

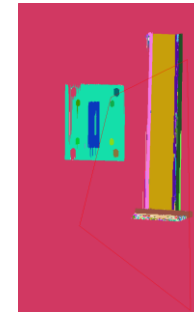
Parts to be located



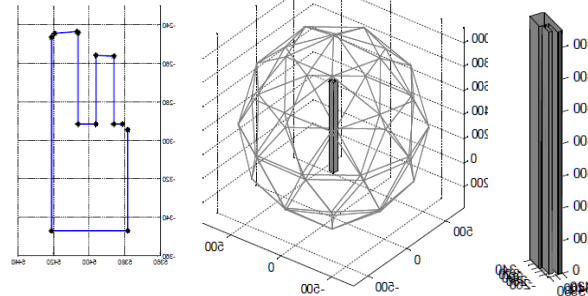
Range map



Segmented surfaces



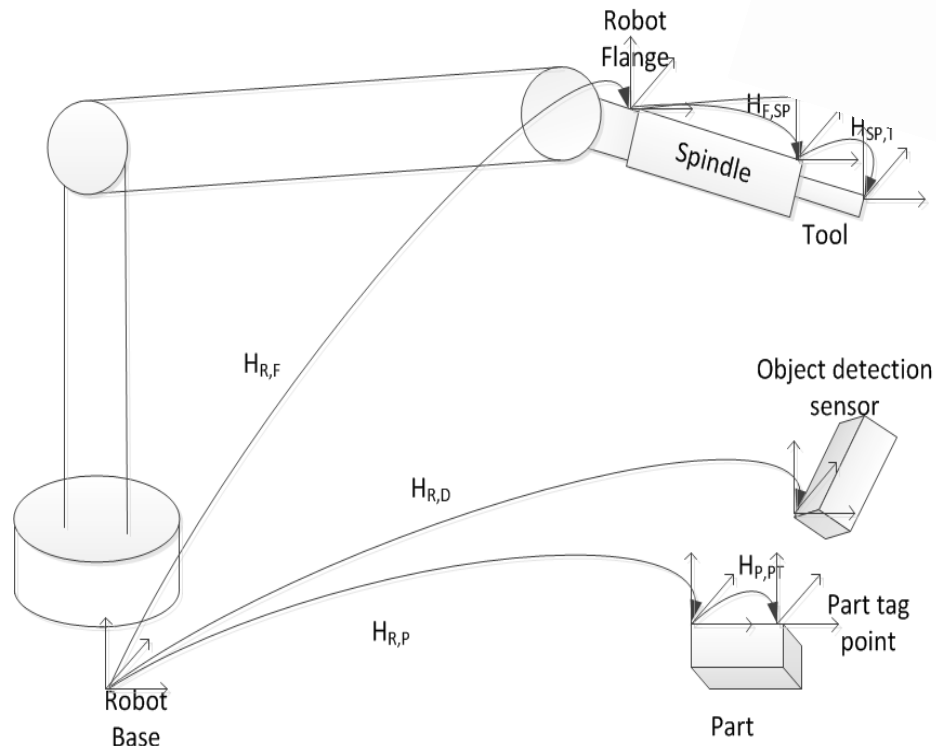
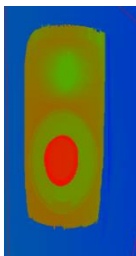
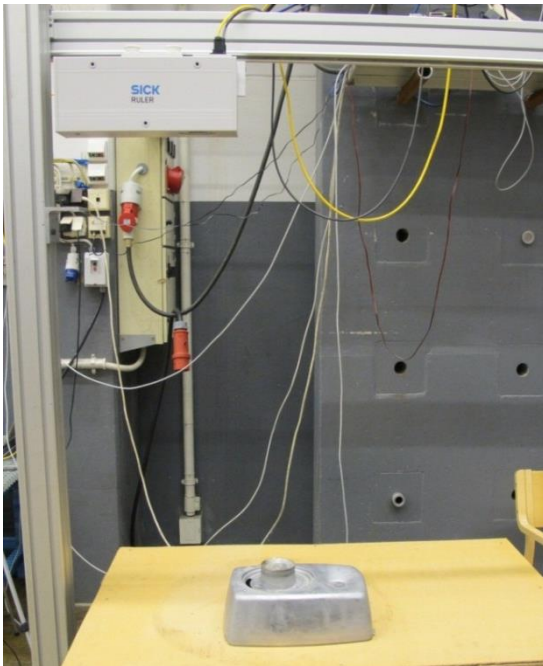
Part identification



Automatic object detection and localizing: Global localization

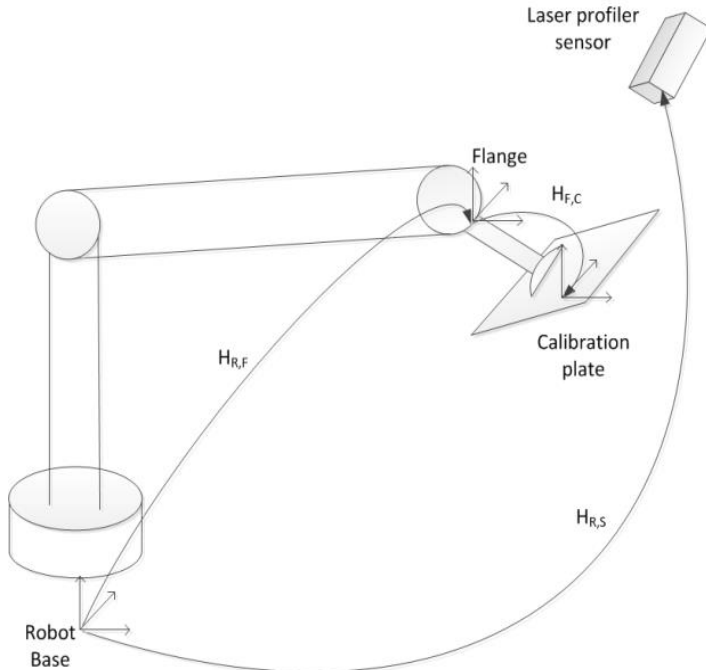
Sick IVP1200 + Linear axis
with servo motor

Coordinate frames in robotic machining with a
sensor fixed in the environment



Hand Eye Calibration (Global localization)

Coordinate frames in Robot-Sensor calibration



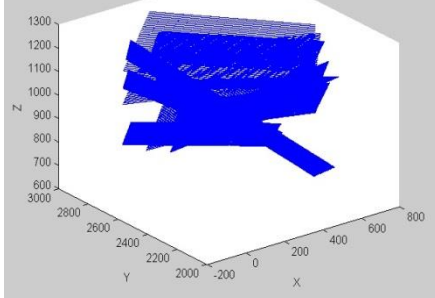
(video)



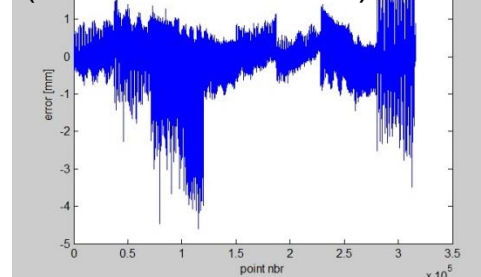
SICK IVP Ruler 1200 laser profiler hand-eye calibration

- Height resolution 0.4 mm, meas range 280 – 1280 mm
- nonlinear measurement model, iterative calculation with linearized model
- 9 parameters (sensor_in_robot; plate_in_RobotTCP)
- at least 5 profile lines; more lines improves accuracy

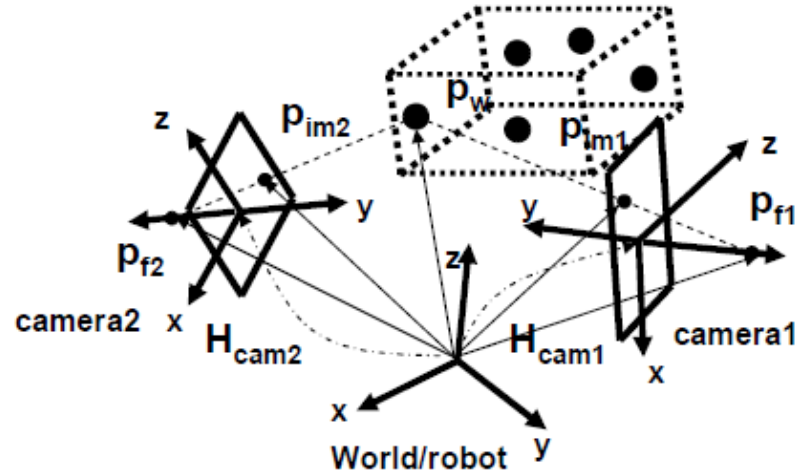
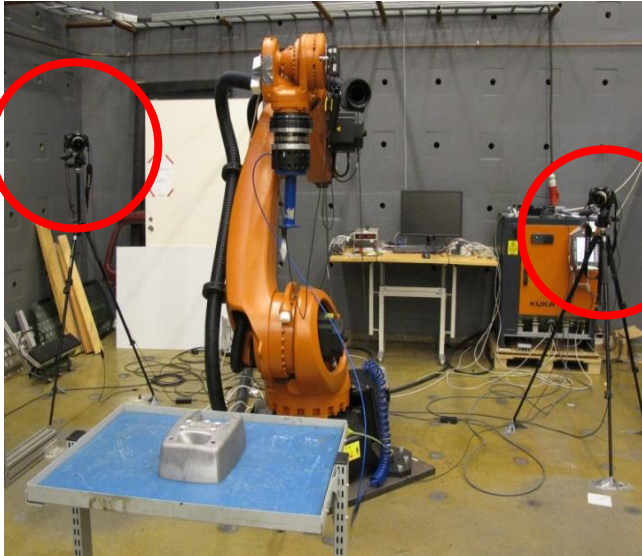
Measured points in robot's base frame after calibration



Remaining error values (z-coordinate values)



Interactive object detection and localization : Global localization



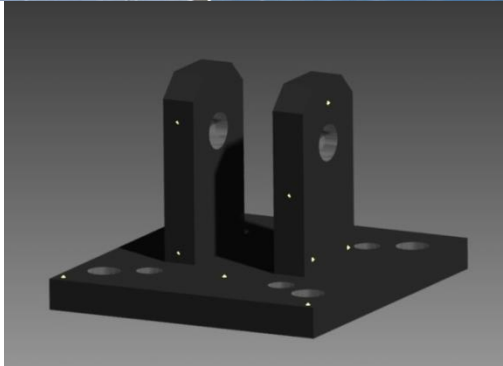
CAMERA system

- Main functions:
 - acquire images from the work object and send them to software via USB
 - HW: Two Canon D550 SLR cameras
 - locating accuracy of squared paper tags in 4 m distance: 1 - 3 mm
- SW:
 - Qt / C++ (Microsoft visual studio 2010)
 - Camera manufacturer proprietary software (Canon)
 - Programming language: Qt / C++
 - EDSDK.dll dynamic library packet

Interactive object detection and localization : Global localization

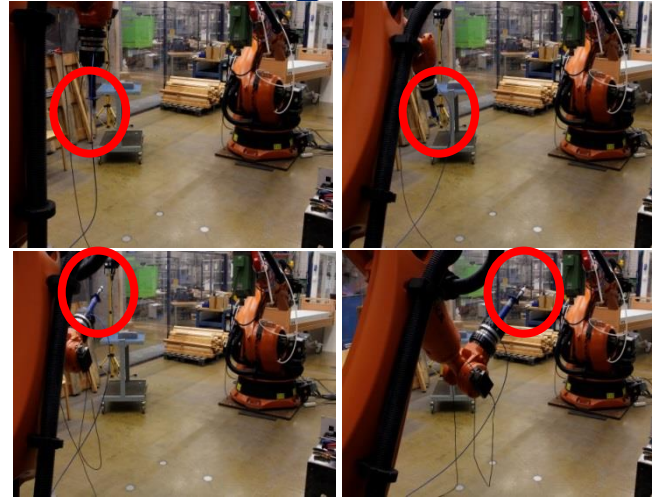


Locating an object with CAD-model
Pairing of detected markers



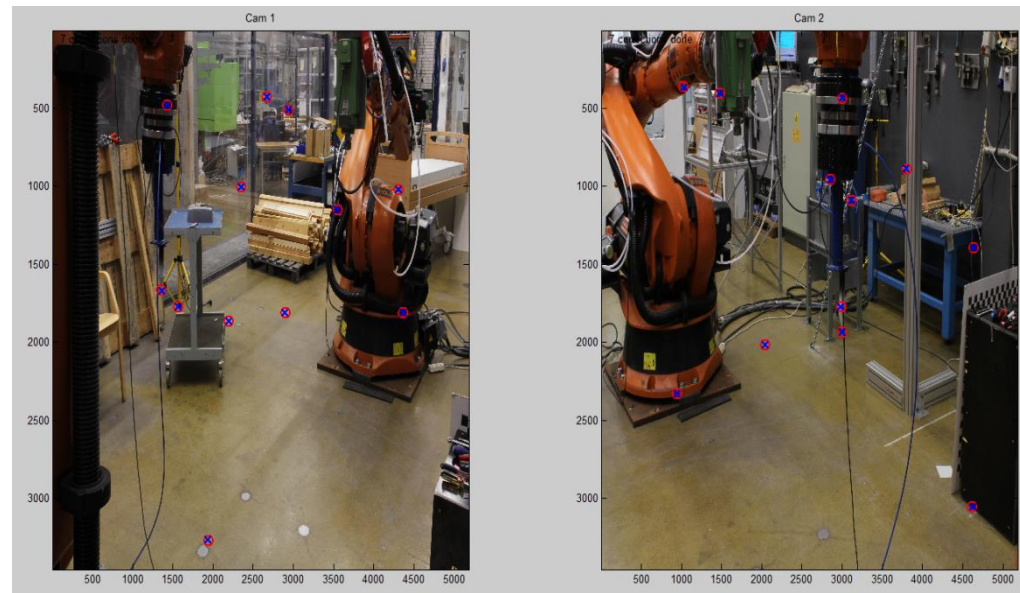
*Points in reference
surfaces in CAD model*

Hand Eye Calibration (interactive global localization)



Cameras & background lighting

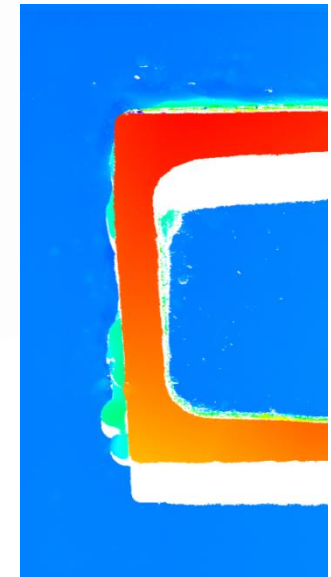
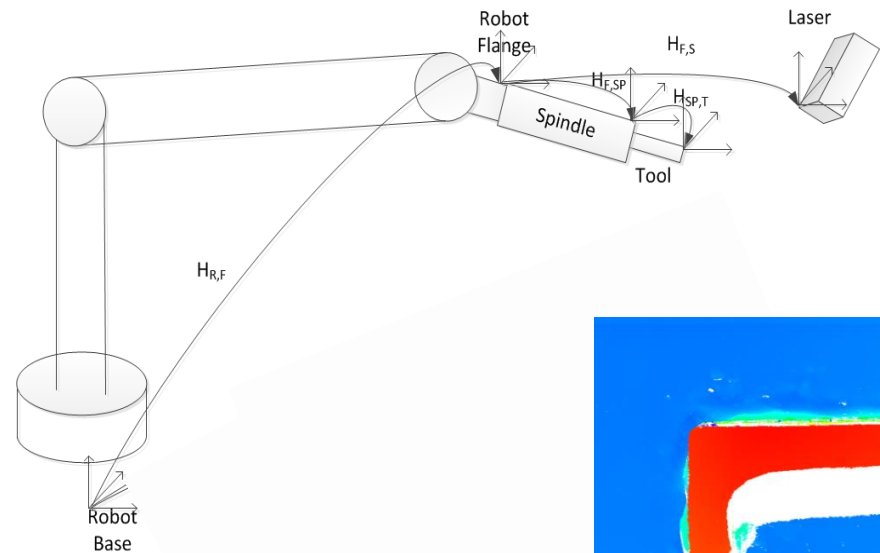
- Calibrate the camera coordinate systems & robot coordinate system (see fig above)
- Measure known points (8 to N) in each camera
- Calculate the camera coord's (6 params per camera) & calibration object location in the robot hand coordinates (3 params)
- Good convergence



Automatic object detection and localizing: Local localization

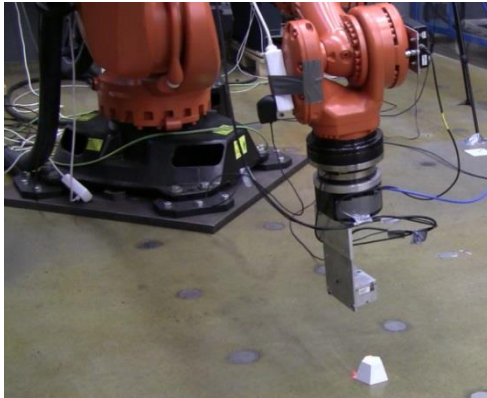
MicroEpsilon 2700 scanner

Coordinate frames in robotic machining with a sensor fixed in the robot wrist.



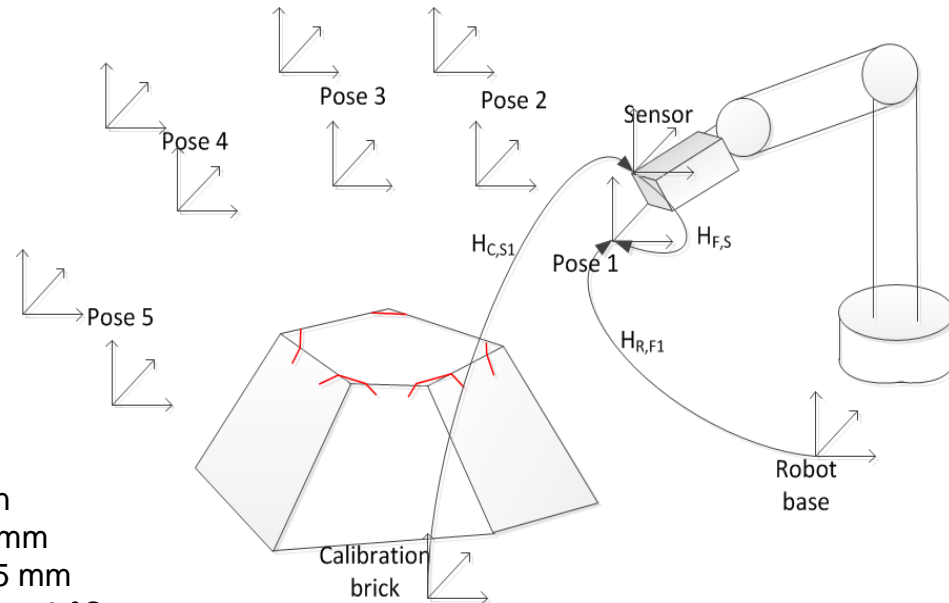
Hand Eye Calibration (Local localization)

The sensor unit in a test frame mounted in the robot wrist



(video)

The principle for calibration measurements of the laser profiler.



MicroEpsilon LLT2700-50 2D laser scanner hand-eye calibration

- Resolution 640 points/profile, line length midrange 50 mm
- Height resolution 0.02 mm, meas. range 175 mm - 225 mm
- Protection class IP 64, Operating temperature 0 °C to + 50 °C
- Calibration: Full 6 DOF transformation, Tsai's hand/eye calibration algorithm [Tsai & Lenz 1989]
- stationary calibration block scanned in five unique poses
- simulations indicate calibration errors as translational error 0.1 mm, with 50 poses, 0.05 mm, with 100 poses, angular error 0.2 mrad both with 50 and 100 poses

Conclusions

- Force/torque sensor modules
 - for machining control
 - for path guidance
- Object detection and localisation sensor systems
 - Automatic global object detection and localization with Hand Eye Calibration
 - Interactive global object detection and localization with Hand Eye Calibration
 - Automatic global object detection and localization with Hand Eye Calibration