

Precision Robot Calibration Using Kinematically Placed Inclinometers

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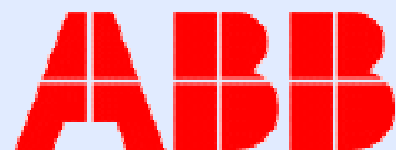


ABB Robotics
Industrial Robots



MIT PERG
Precision Engineering



Project Overview

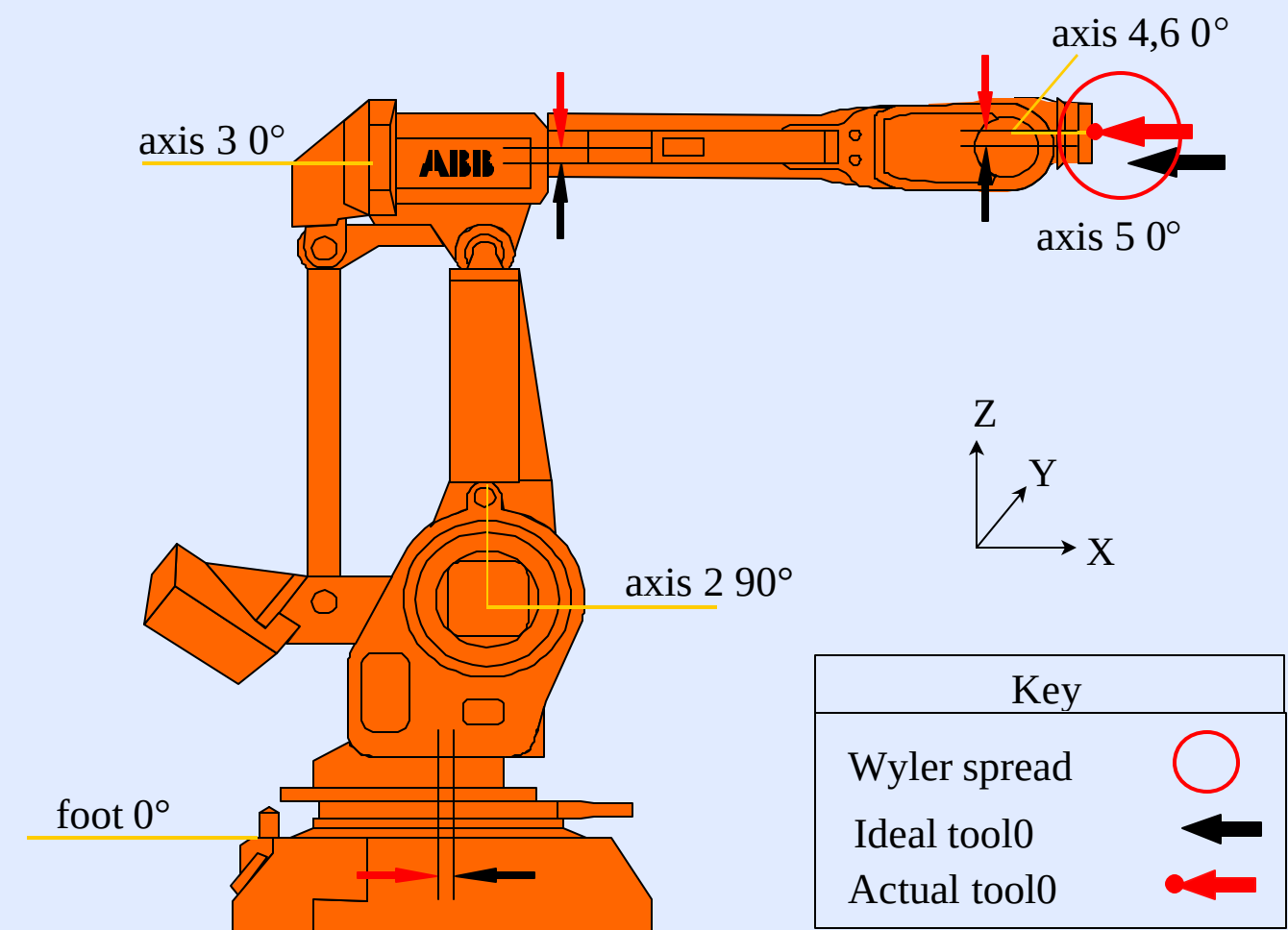
- Functional requirement
 - Calibrate the robot home position by leveling – align each axis to be perpendicular or parallel to gravity vector
- Project aims
 - Determine the accuracy of the existing robot leveling system
 - Design and construct a new leveling system with significantly improved accuracy
 - Provide a simple to use software automation tool to allow rapid and consistent calibrations
- Project phases
 - Prototype 1
 - Mount 2 sensors on an improved mounting bracket
 - Automate with PC based software
 - Prototype 2
 - Design and build a simple concept unit using kinematic couplings
 - Automate with controller based software
 - Prototype 3
 - Design and build accurate customer demonstration unit
 - Product
 - Integrate into the existing ABB product line

Existing System

- Current leveling process
 - Mount Wyler ZeroTronic™ inclinometers on sensor plates
 - Place mounting plates on robot structure
 - Place reference sensor plate on robot foot
 - Place leveling sensor plate on mounting plates on robot structure
 - Move (jog) robot manually until leveling sensor matches reference sensor
 - Update home position in controller

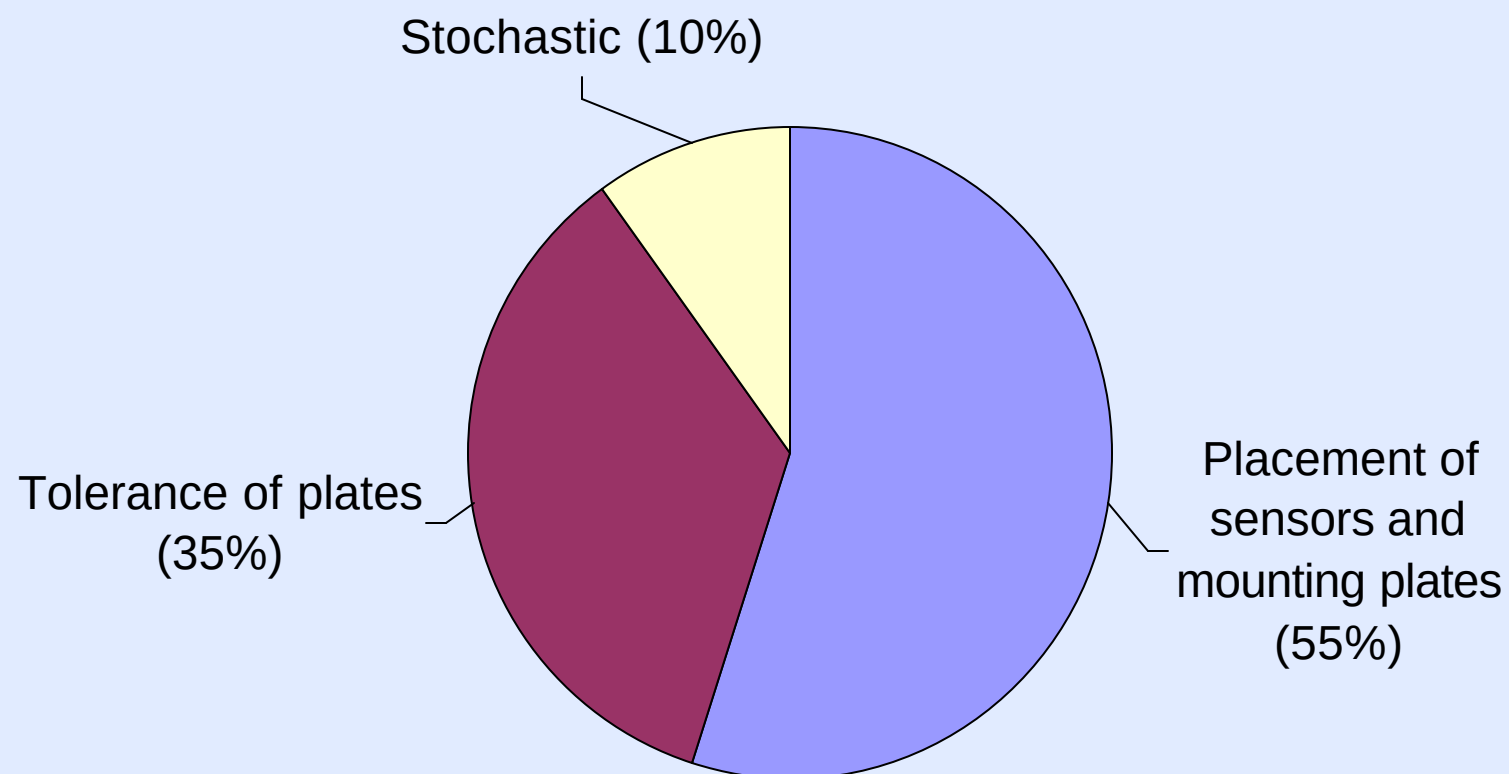
- Problems

- Poor process repeatability
- Difficult to accurately place mounting plates
- Large user-dependent errors from manual jogging of robot



Design Requirements

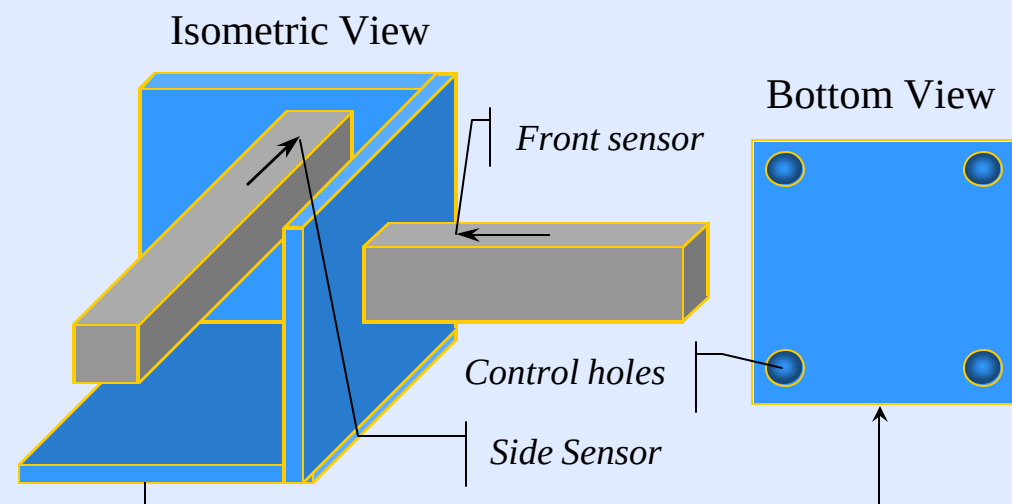
- Analysis of existing system
 - Recalibration errors
 - At robot flange $\approx \pm 1.0\text{mm}$
 - At 350mm tool $\approx \pm 1.5\text{mm}$
 - Error breakdown



- Design goals
 - Improve process repeatability
 - No separate mounting plates or components
 - High accuracy mounting unit
 - Compact and compatible with existing robot variants
 - Absolute measurement not relative
 - Software process automation
 - Recalibration error $\leq \pm 0.2\text{mm}$

Prototype 1

- Proof of concept
 - Mount sensors on single structure
 - Set reference levels on robot foot
 - Place on existing mounting plates on wrist, lower arm, upper arm and flange
- Software automation
 - PC based software automation of controller and sensors
 - Calculate and apply axis adjustments



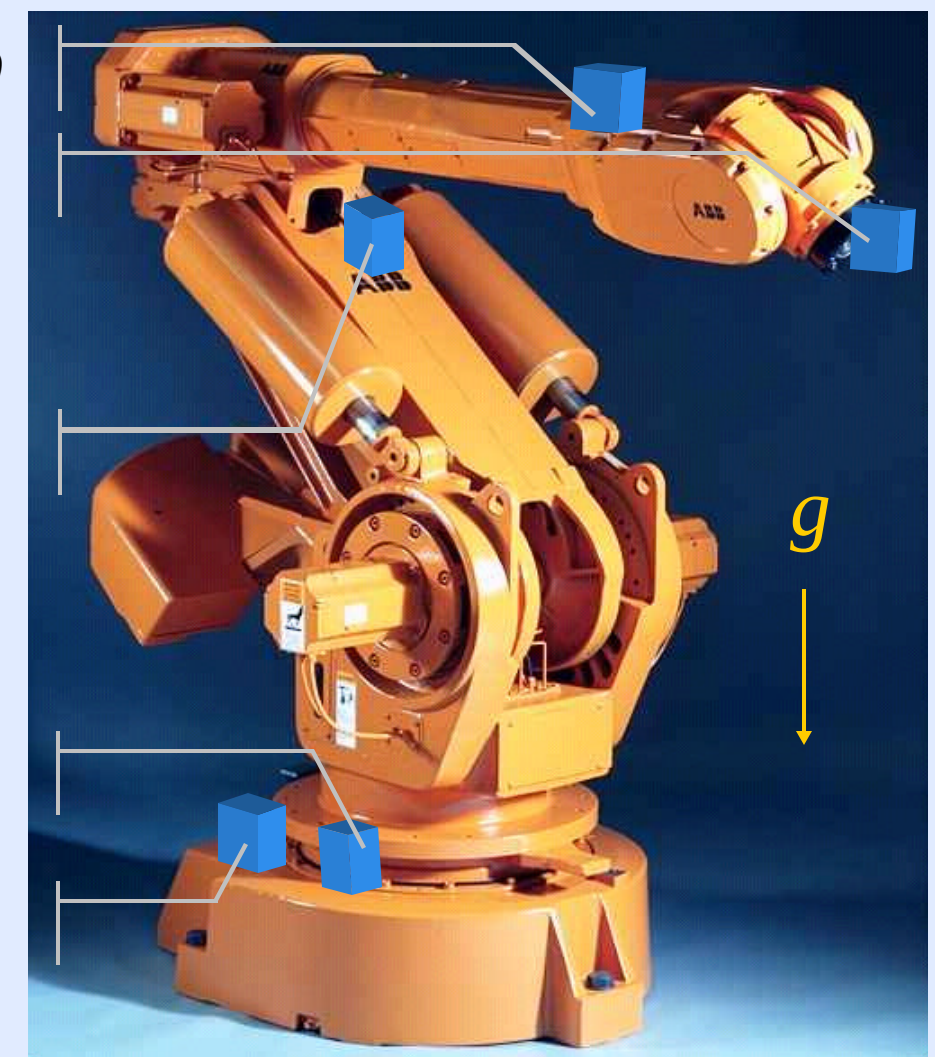
Prototype 1 unit



Software automation

- Software automation
 - PC based software automation of controller and sensors
 - Calculate and apply axis adjustments

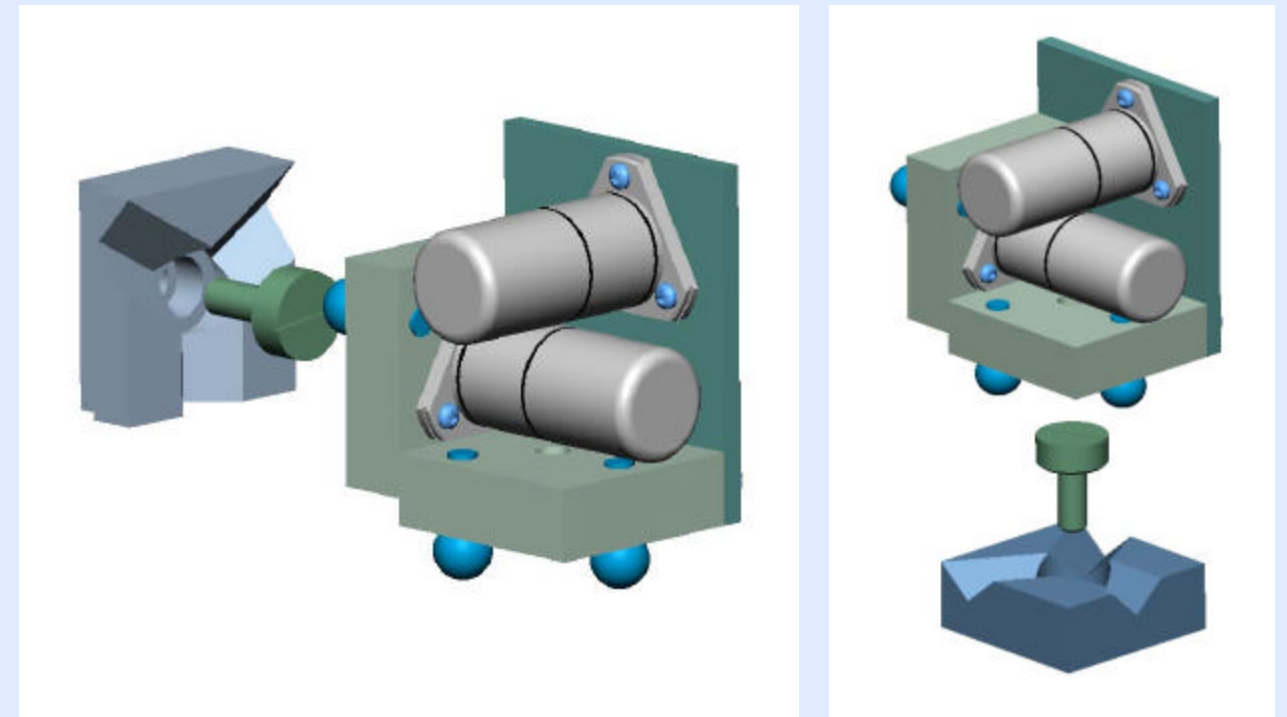
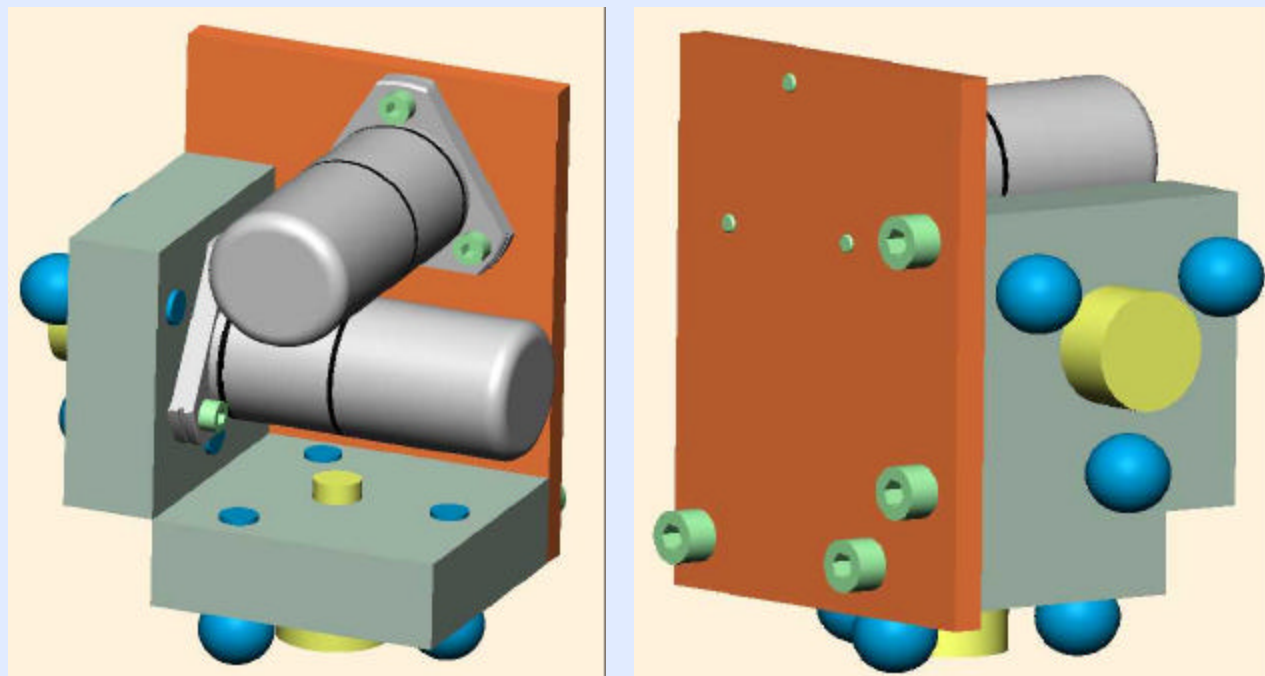
- Wrist (axes 3–4)
- Flange (axes 5–6)
- Lower arm (axis 2)
- Under body (axis 1)
- Foot (reference)



IRB6400R-2.5m-150kg

Prototype 2

- Cube construction
 - Mount magnets and tooling balls on separate steel plates
 - Assemble plates into cube and mount sensors
 - Use kinematic couplings for high accuracy placement on robot structure
- Plate construction
 - Machine separate grooved plates
 - Bolt onto existing mounting locations in robot structure
 - Use hardened steel plates to maximize magnet preload force and minimize long-term wear

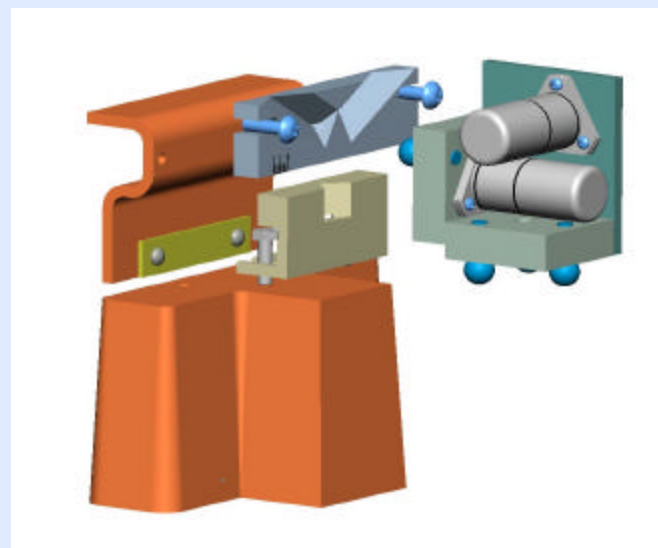


Axis 2 mount

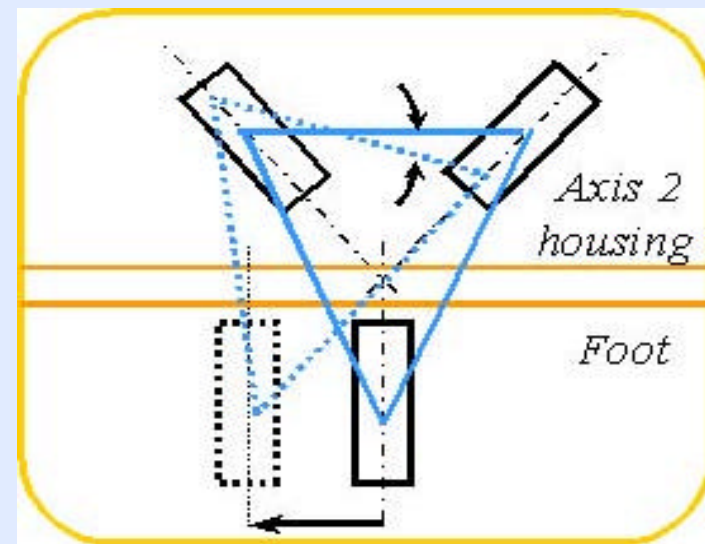
Foot/Wrist mount

Prototype 2

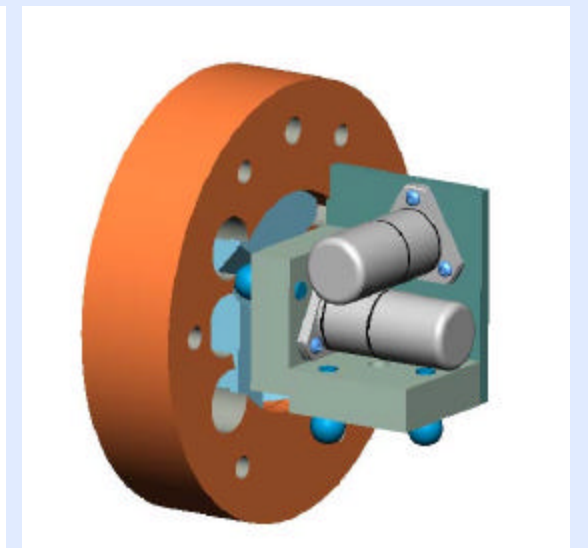
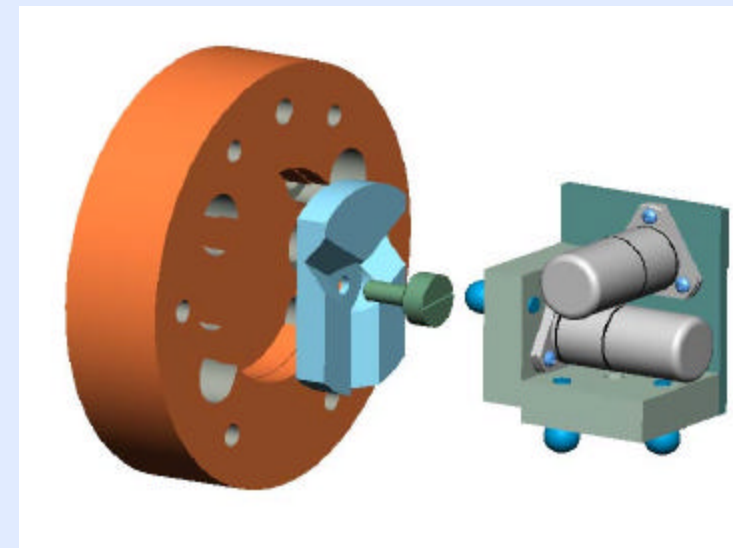
- Axis 1 mounting
 - Measure rotation of axes parallel to the gravity vector
 - Use dynamic kinematic coupling to ensure accurate measurement
 - Magnet preload holds unit in place and allows accurate re-alignment within coupling geometry during robot motion
- Axis 2, wrist mounting
 - Use standard, stationary groove kinematic couplings
- Flange mounting
 - Axes 5 and 6 calibration highly sensitive to cube orientation
 - Press-fit groove plate into robot flange as an alternative to adaptor plates



Axis 1 mount



Dynamic kinematic coupling

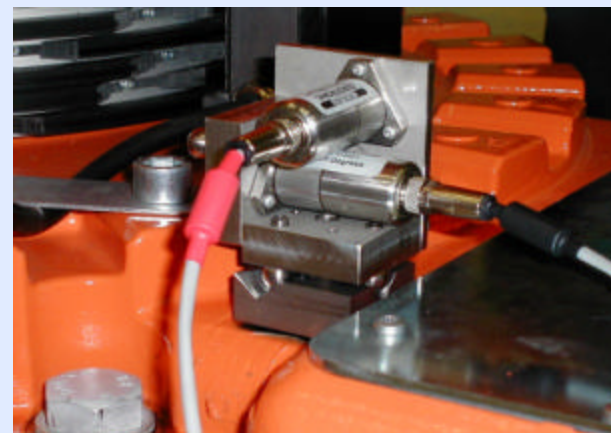


Flange mount

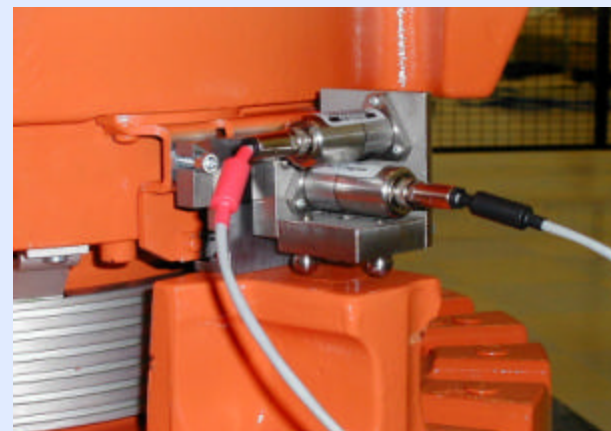
Prototype 2

- Test results
 - Tested at BMW Germany on an IRB6400R-2.5m-150kg robot
 - Average recalibration error = 0.4mm

Foot



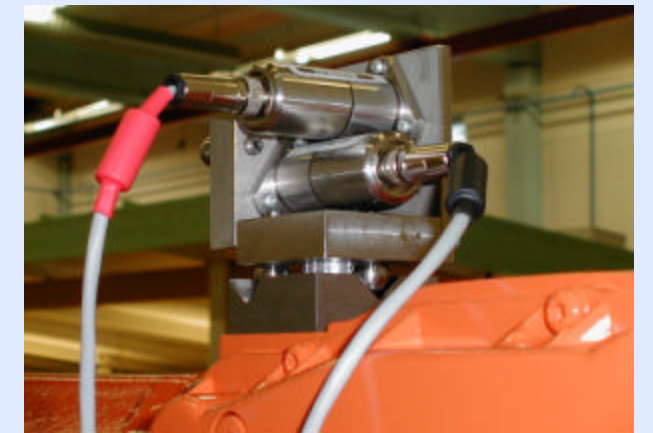
Axis 1



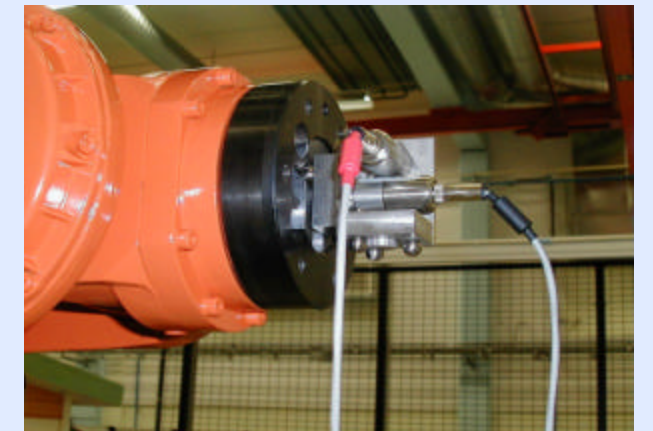
Axis 2



Wrist

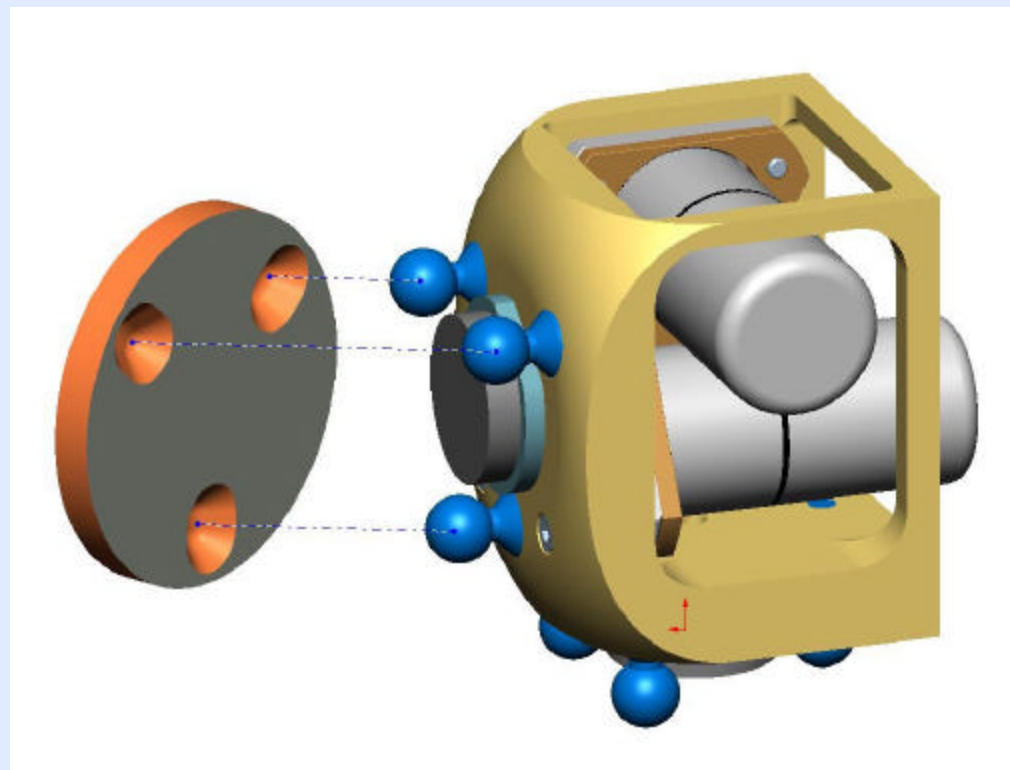


Flange



Prototype 3

- Conceptual Design
 - Mount sensors in a single-piece open cube structure
 - Magnet bolted to front and bottom surfaces of cube structure
 - Smaller grooves and thinner plates for reduced profile



Open cube structure and low profile groove plates

- Final Design
 - Solid cube structure requires only three precision machined surfaces
 - Size: 40×40×60mm. Weight: 500g
 - Full software automation implemented in robot controller
 - Recalibration accuracy = 0.2mm



Product Options

- Upgrade kit for existing robots
 - Bolt groove plates onto existing mounting locations
 - Machine grooves directly into flange
- Integrated product for new robots
 - Standard calibration method for new heavy duty robot IRB7600
 - Machine grooves directly into robot structure

