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

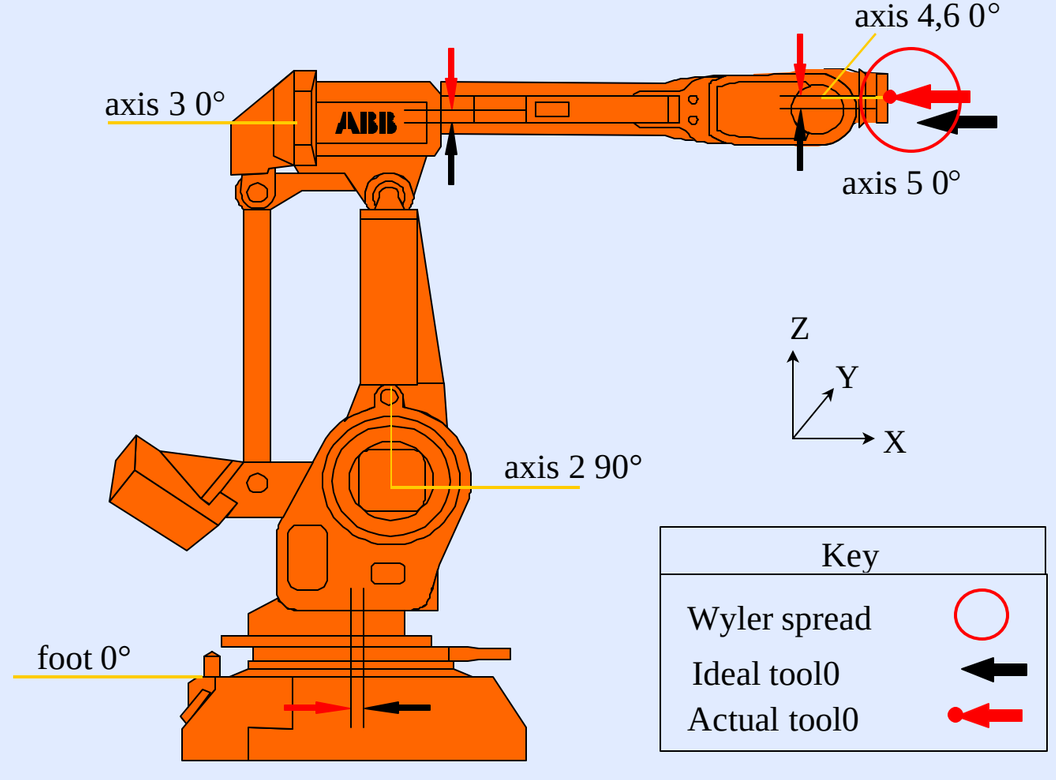
- Current leveling process
  - Mount Wyler ZeroTronic™ inclinometers on sensor plates
  - Place mounting plates on robot structure
  - Place reference sensor plate on robot foot
  - Place leveling sensor plate on mounting plates on robot structure
  - Move (jog) robot manually until leveling sensor matches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

reference sensor

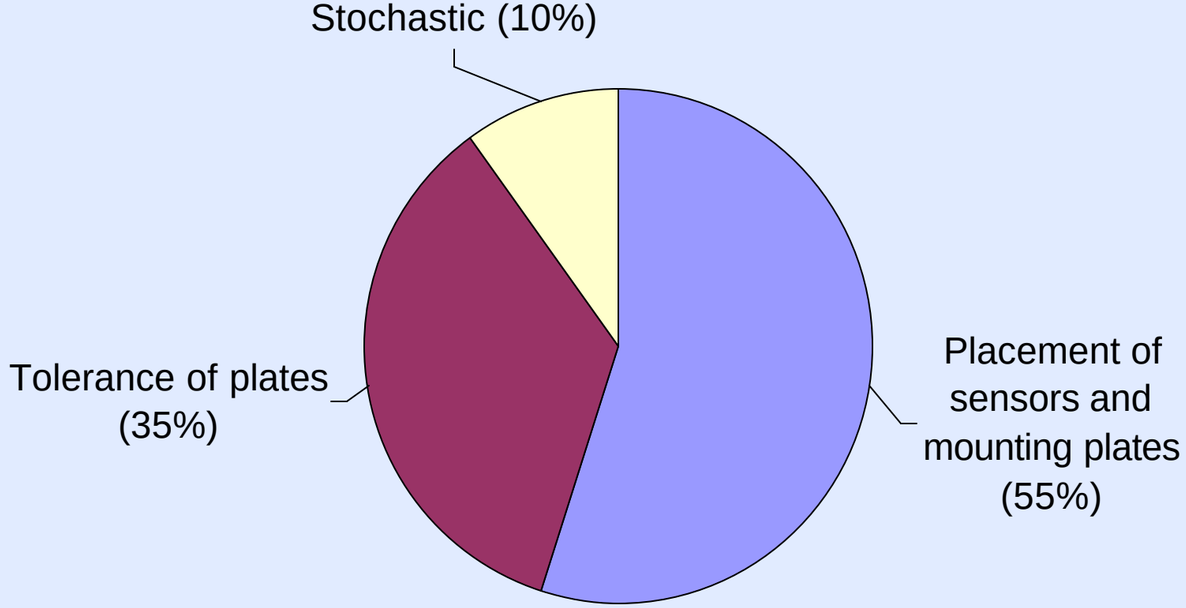
leveling sensor

hand unit



Design Requirements

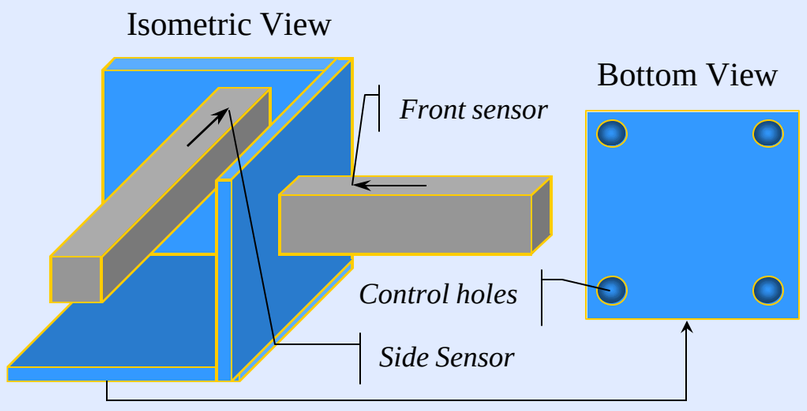
- Analysis of existing system
  - Recalibration errors
    - At robot flange ≈ ±1.0mm
    - At 350mm tool ≈ ±1.5mm
  - Error breakdown



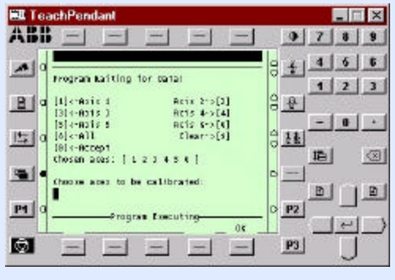
- Design goals
  - Improve process repeatability
  - No separate mounting plates or components
  - High accuracy mounting unit
  - Compact and compatible with existing robot variants
  - Absolute measurement not relative
  - Software process automation
  - Recalibration error ≤ ±0.2mm

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



Prototype 1 unit



Software automation

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

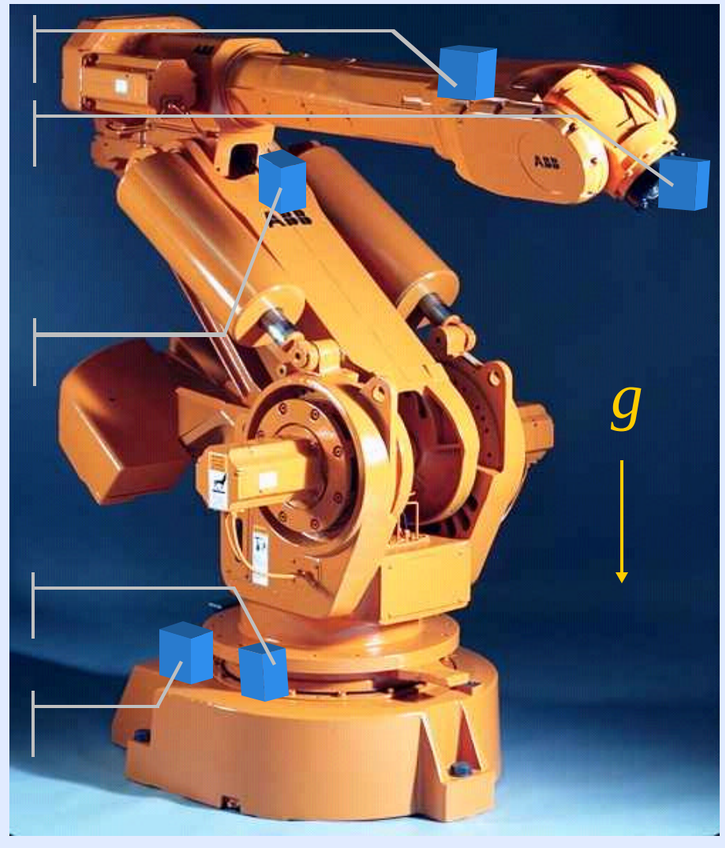
Wrist (axes 3–4)

Flange (axes 5–6)

Lower arm (axis 2)

Under body (axis 1)

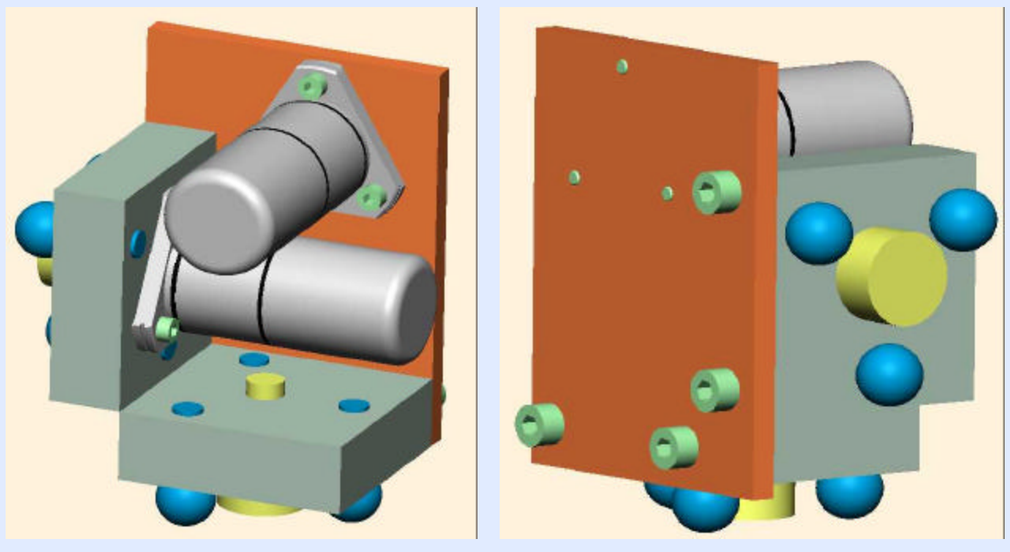
Foot (reference)



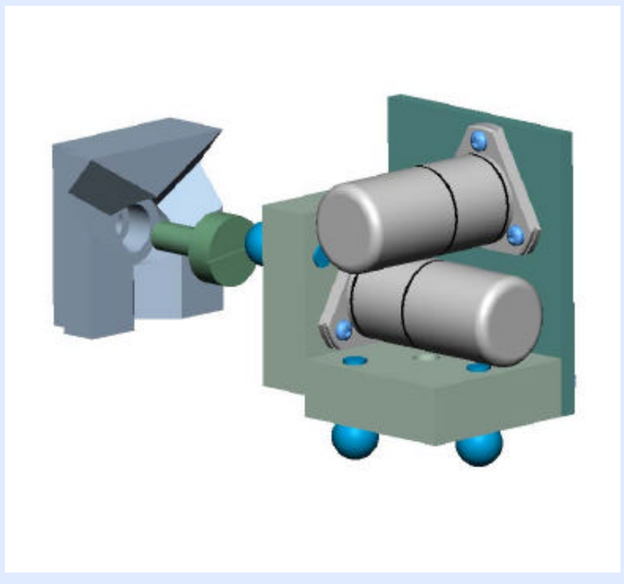
IRB6400R-2.5m-150kg

Prototype 2

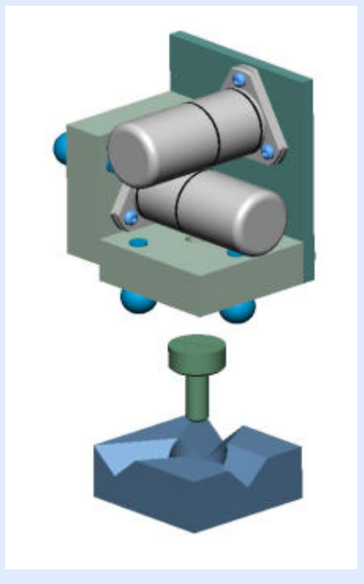
- Cube construction
  - Mount magnets and tooling balls on separate steel plates
  - Assemble plates into cube and mount sensors
  - Use kinematic couplings for high accuracy placement on robot structure



- 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



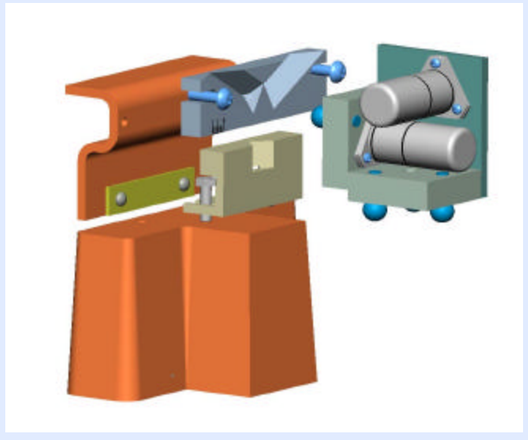
Axis 2 mount



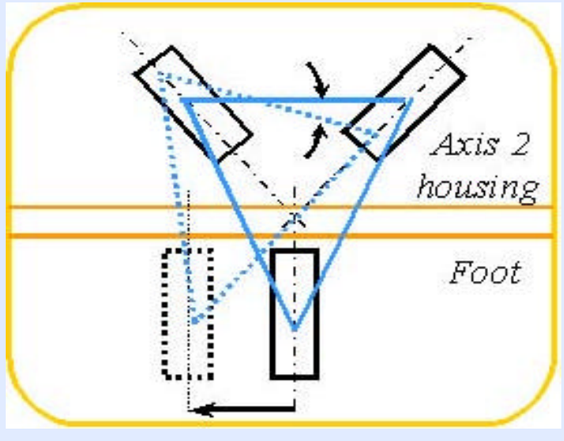
Foot/Wrist mount

Prototype 2

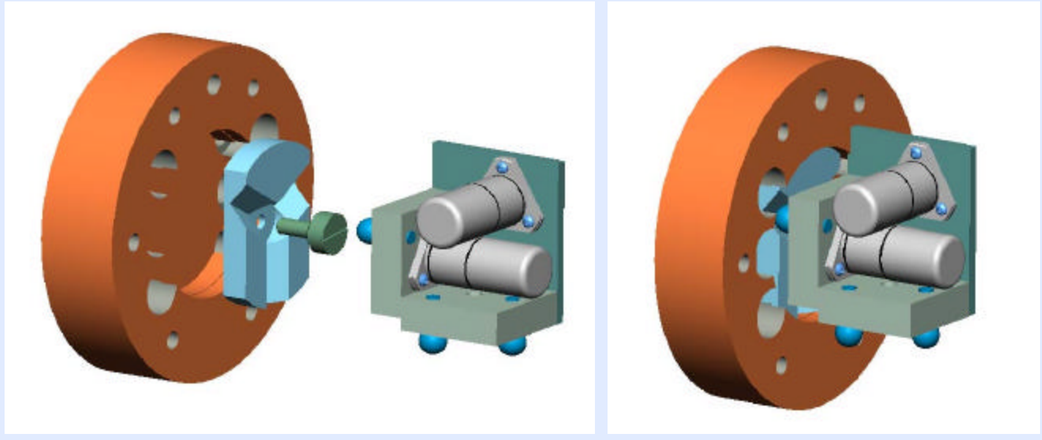
- Axis 1 mounting
  - Measure rotation of axes parallel to the gravity vector
  - Use dynamic kinematic coupling to ensure accurate measurement
  - Magnet preload holds unit in place and allows accurate re-alignment within coupling geometry during robot motion
- Axis 2, wrist mounting
  - Use standard, 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

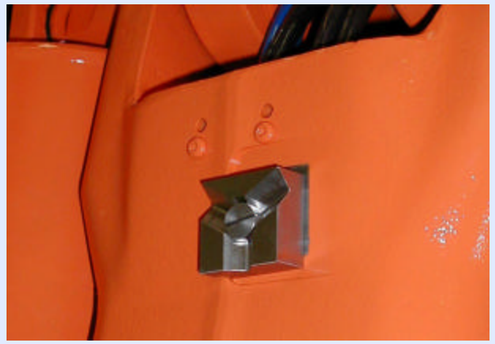


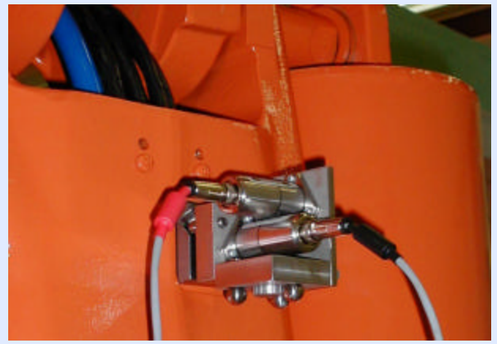
Flange mount

Prototype 2

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

Axis 2

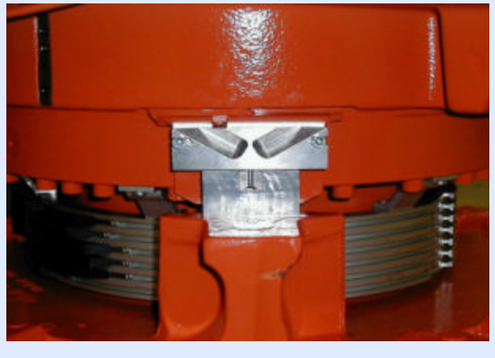


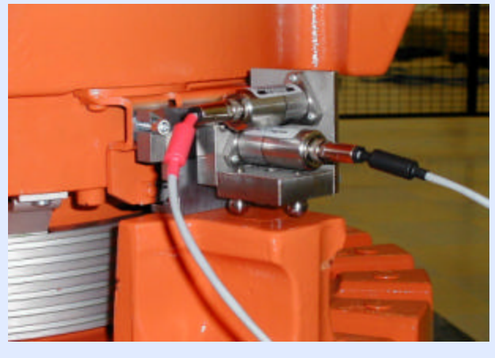


Foot

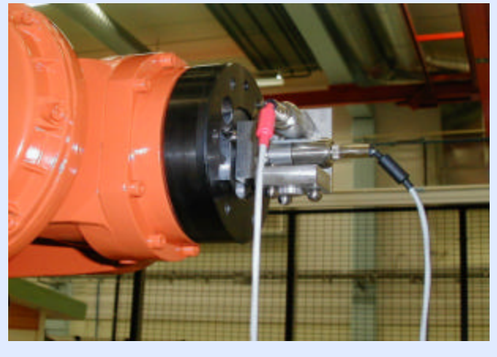
Wrist

Axis 1



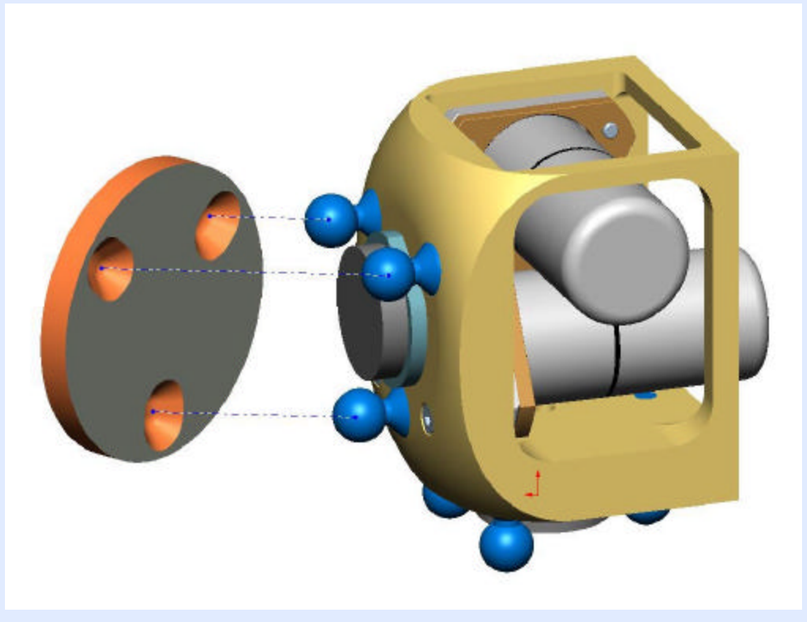


Flange



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

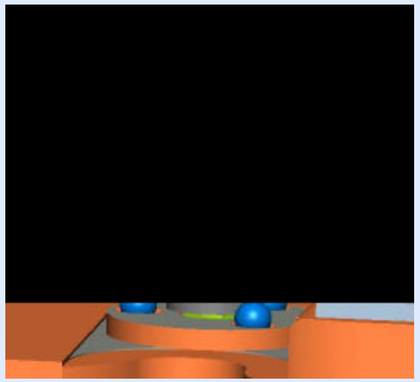


Open cube structure and low profile groove plates

- 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



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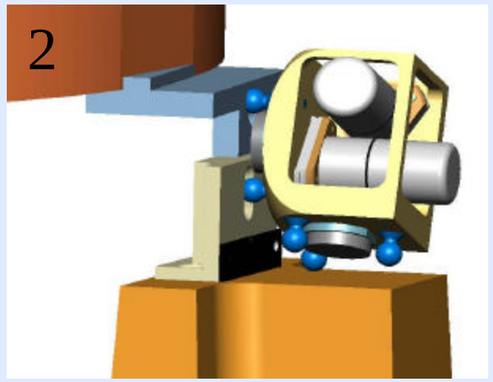

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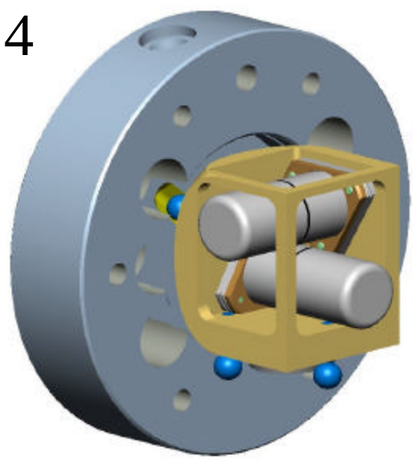

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1. Foot
2. Axis 1
3. Wrist
4. Flange
5. Axis 2

- Integrated product for new robots
  - Standard calibration method for new heavy duty robot IRB7600
  - Machine grooves directly into robot structure