YASKAWA

Yaskawa America Robotics Division

INTEGRATED INTELLIGENT INNOVATIVE

NIST

Current Methods and Approaches to Improve Robot Accuracy

presenter:
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Yaskawa
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YASKAWA

YASKAWA ELECTRIC CORPORATION

BUILDING ON OVER 100 YEARS OF INNOVATION

- Established: July 1915
- Headquarters: Kitakyushu, Japan
- Annual Sales: $4 Billion USD
  (2024 FY)
- Employees: ~14,000
- Over 600,000 Motoman® robots installed worldwide
- Production facilities in multiple countries

Yaskawa Headquarters, Kitakyushu, Japan


Yaskawa Innovation Center

Yaskawa America, Inc.

Motoman Robotics Division

- Established: 1989
- Headquarters: Dayton, Ohio
- Employees: 650
- 10 offices located strategically throughout the Americas

DRIVES & MOTION DIVISION
WAUKEGAN, ILLINOIS

World’s largest manufacturer of AC drives and motion control products, including adjustable frequency drives, servo amplifiers, servomotors and machine controllers

490,000 sq. ft. U.S. Facility Headquarters, featuring stocked robots, $35M of spare parts, pre-engineered solutions, custom systems and standard product support .

Deliver Real-World Results

Innovations for Diverse Industries

Installed base spans virtually every major industry

- Alternative Energy
- Appliances
- Automotive
- Consumer Products
- Education
- Electronics
- Furniture and Fixtures
- Harvesting / Farming
- Life Sciences
- Machinery
- Medical
- Metal Products
- Off-road / Agriculture
- Paper and Printing
- Pharmaceuticals
- Plastics and Rubber
- Recreational Equipment
- Warehousing / Logistics
- Textiles
- Wood Products
- and more

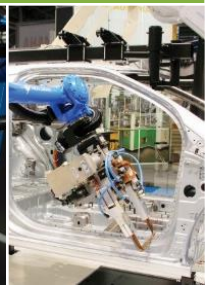
Deliver Real-World Results

Extensive Range of Applications




Greatest level of application depth in supporting and applying robotic solutions to optimize operations in nearly any scenario





TRADITIONAL APPLICATIONS

Arc and Spot Welding
Assembly
Coating | Dispensing
Material Cutting
Material Removal
General Handling
Picking | Packing | Palletizing

EMERGING APPLICATIONS

AI Inspection
Biomedical
Collaborative Robots
Mobile Robotics
Parcel Sortation
Ultrasonic Trimming & Finishing
Vertical Farming

Standard Products

full line of
ROBOT MODELS
for broad scope of applications

Variety of Robot Models

- 4-, 5-, 6-, 7- and 15-axis
- Payload capacity up to 900 kg
- Collaborative models
- Delta and SCARA type models
- Single- and dual-arm configurations

OUR STANDARDS GROUP MAKES AUTOMATION EASY

ROBOTS | CONTROLLERS | POSITIONERS | DRIVES | SENSORS | SOFTWARE | CONNECTIVITY | SAFETY | STANDARD SOLUTIONS

Standard Products

STANDARD,
PRE-ENGINEERED SOLUTIONS

minimize engineering and integration risk

Engineered to Perfection

ArcWorld® Solutions

- Pre-assembled, shipped ready-to-use
- Seamlessly integrate robots, welding equipment, servo-controlled positioners, workcell safeguarding and software
- Available in a variety of configurations:
  - Basic space-efficient designs that are ideal for low-volume fabrication
  - Larger workcells that offer multiple robot configurations and heavy-duty positioners for processing of large, heavy parts

OUR STANDARDS GROUP MAKES AUTOMATION EASY

ROBOTS | CONTROLLERS | POSITIONERS | DRIVES | SENSORS | SOFTWARE | CONNECTIVITY | SAFETY | STANDARD SOLUTIONS

Custom Solutions

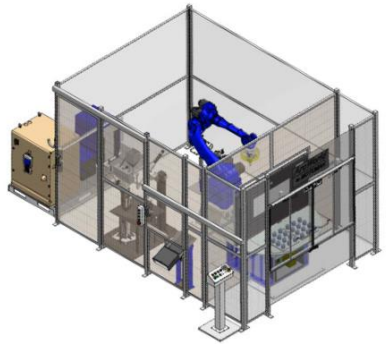
fully integrated, innovative

ROBOTIC SOLUTIONS

meet complex, difficult or unique manufacturing challenges

Advanced Systems Group

- Expert team members – averaging 15 years of experience - with knowledge of various industries, automation and third-party technologies
- Experienced engineers concept, design and execute solutions tailored to your exact requirements – on time and on budget
- Project managers provide a single point of communication, manage systematic project execution and oversee quality assurance



3-D modeling software (SolidEdge®) and simulation tools (MotoSim® EG-VRC) used to perform reach studies, cycle time checks and to confirm cell layout

Technology Advancement

Dedicated to Product Development

Demo Lab (Miamisburg, Ohio)

- Custom demos to validate solutions for challenging applications
- Yaskawa-focused, application-based training for internal and external customers
- Product testing and evaluation of new products and ancillary equipment

Yaskawa Innovation (Austin, Texas)

- Advance the use, functionality and knowledge of existing products
- Develop technologies that make industrial robots easy to use
- Lead innovation targeted at new markets and applications
- Drive development across global Yaskawa R&D facilities

Current Methods and Approaches to Improve Robot Accuracy

Why are Robots not accurate,

when they're so repeatable? (+/- 0.001")

Because a robot is a series of linked springs and of mechanical assembly.

Factors that effect accuracy

- Manufacturing tolerance stack-up
- Bending deformations undergone by the robot links under load
- Reducer backlash
- Thermal effects
- Wear and tear

Typical accuracy is 10-50x worse that of the robots positional repeatability spec. (0.02mm vs. 0.20 -1.0mm)

- GP25 1.7M reach, 25kg payload

Calibration

Robot calibration is the process of making sure your robot's movements match what you programmed it to do - as simple as that!

- The basic calibration process, involves using a precise measuring instrument to detect the real position of the robot.
- This is compared against the commanded position and a set of rules is generated to convert the commanded position to a more accurate one during programming.
- Results depend on the precision of the measuring instrument and the quality of set-up procedure

Methods to improve accuracy

When a Robot Isn't As Accurate As You'd Like

- **Mechanical methods**
  - Increase stiffness of robot links
  - Reduce manipulator weight
  - Use high precision reducers (hand picked)
- **Control-based methods**
  - Pointer and Sphere (Good)
    - Corrects for mechanical inconsistencies
  - String /Gimbal encoder (Better)
    - Uses points within a larger work area
    - Can compensate for additional factors (i.e., friction compensation)
  - Laser Tracking (Best)
    - Best results. Usually performed on-site. Can measure entire work envelope. Expensive and time consuming

DH (Denavit and Hartenberg)

$$
{}^{n-1}T_n = \begin{bmatrix} \cos\theta_n & -\sin\theta_n & 0 & a_{n-1} \\ \sin\theta_n \cos\alpha_{n-1} & \cos\theta_n \cos\alpha_{n-1} & -\sin\alpha_{n-1} & -d_n \sin\alpha_{n-1} \\ \sin\theta_n \sin\alpha_{n-1} & \cos\theta_n \sin\alpha_{n-1} & \cos\alpha_{n-1} & d_n \cos\alpha_{n-1} \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

One approach for affordable “Best” calibration

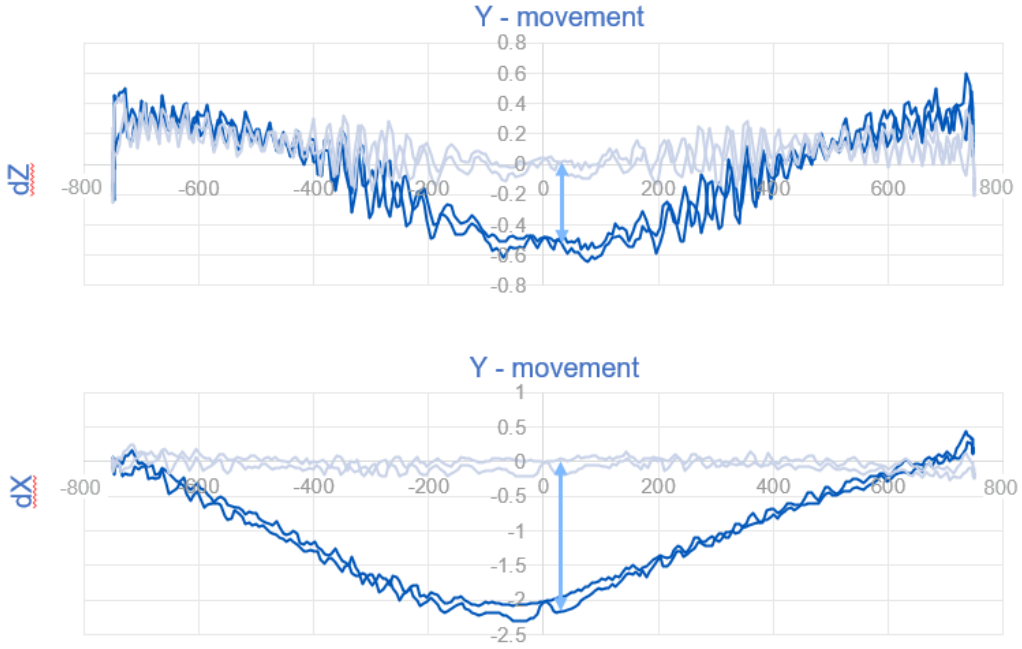
Yaskawa’s **Absolute Accuracy** factory laser-calibration option

- Performed Ex-Works Factory
- Benefits:
  - Significantly increased pose accuracy up to approximately 0.2 mm*
  - Minimizes the gap between the real robot and its digital twin
  - Predictable and easy robot installation
  - Increased operational reliability and efficiency
  - Consistent and accurate results in the application

* depending on robot size and type

One approach for affordable “Best” calibration

Demonstration of Linearity improvement



- Both graph‘s show the way the robot moves along the Y-axis and how the deviations in the Z and X directions appear (in this example a HC10DTP).
- The dark blue graphs represent the linearity performed before the calibration.
- The light blue graphs the linearity performed after the absolute calibration has been performed.

Graph values:

— Linearity **BEFORE** calibration

— Linearity **AFTER** calibration

One approach for affordable “Best” calibration

Before and after accuracy results

Robot type	BEFORE Absolute Accuracy (mm)	AFTER Absolute Accuracy (mm)
GP180-120	0,89	0,29
GP35L	1,05	0,19
GP7	1,03	0,31
GP50	0,91	0,19
GP12	1,18	0,19
HC10	1,52	0,38
HC20	1,65	0,28

Absolute Accuracy calibration method

- Compensation of a robot’s mechanical tolerances and structural elasticities under various loads is a complex problem and requires a suitable mathematical model.
- This model includes geometric (DH parameters) and elasticity compensation parameters (spring constants) which are determined by a corresponding measurement process during calibration.
- The YASKAWA Absolute Accuracy Option compensates positions internally in the controller, resulting in a significantly improved pose and path accuracy.
- The newly calibrated accuracy and the individual compensation parameters are recorded and confirmed by a certificate.

One approach for affordable “Best” calibration

Calibration Certificate & Label

- Each robot calibrated with absolute accuracy, receives an **individual certificate** with all the information concerning:
  - robot serial number, robot and controller type
  - all calibration and measurements details
- For **easy identification** in the field, calibrated robots are marked with a **special label** above serial plate

Alternative Approaches for consideration

Yaskawa does not currently offer these approaches

- **Accuracy improvement** using **secondary encoders** measuring the position on the output side of a gear reduction.
  - A select few companies offer a custom-built solution
    - Modifying a standard 6-DOF robot manipulator and custom controller.
    - Not mass produced
    - Expensive
    - Long lead times
- Implementation of **Artificial Intelligence, more capable cameras, tactile sensors, etc.**
  - Enable robots to better understand their environment, detect and recognize objects, and interact with the world
    - Start with a calibrated robot
    - Develop an AI driven, real time sensing solution
    - -

Robot Accuracy - Standards/Guidelines

Considerations

- Define what type of applications require robot accuracy.
  - Milling, Drilling, 3D Printing, Micro-Assembly, Testing, Inspection, Autonomously generated Path and Position.
    - Which applications require Pose accuracy?
    - Which applications require Path accuracy?
      - The above require different testing
  - What is the Positional Accuracy requirement for each application?
    - Good, Better, or Best?
      - Is Best good enough (+/- 0.2 mm) ?
      - Could benchmark the calibration method/tool used. Saving time and capital.
  - Will NIST select/mandate certain calibration equipment as a “must have” to certify?
  - What would be the robot OEM’s certification requirements?

Thank you

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