Preparing industrial robots for high-accuracy applications

For high-accuracy manufacturing applications, industrial robots offer significant cost, space and flexibility benefits. Industrial robots enable processes which would be impossible due to limited accessibility and reach of traditional methods. However, most out-of-the-box industrial robots are unable to perform to the desired repeatability or accuracy. Sub-1 mm accuracy is unachievable without appropriate set-up and calibration. To achieve accuracy performance in the range of tens of microns, the modes of error contribution must be identified and addressed. This white paper outlines the factors impacting robot accuracy, the differences between performance metrics and how the Renishaw RCS product series can improve robot set-up, diagnostics and validation.

A history of robot accuracy

For seventy years, industrial robots have been the workhorses of the manufacturing industry. With appropriate maintenance, these repeatable devices can conduct the same operations for tens of thousands of hours. Demand for higher accuracy robots is increasing, driven by the need for improved servo drives, gearbox design, lightweight construction materials, and inclusion of secondary encoders. Modern controllers target tighter control loops and path planning software has improved. A path performance of less than 1 mm can be regularly achieved with proper set-up. However, many applications require a path performance of less than 500 µm, and in some cases, less than 100 µm:

- Precision / micro assembly tasks
- Laser welding and cutting
- Machining, cutting and deburring tasks
- Precision coating
- 3D printing and composite layup

These applications are modeled in CAD and then simulated in dedicated software. Achieving the desired tolerances can be challenging even digitally. When replicated in the physical world, set-up can introduce further physical errors that impact performance. The differences between the simulation and real-world application must be recorded and evaluated to enable offline programming and minimise the impact on accuracy.

Factors impacting robot accuracy

Errors introduced during robot and part set-up can significantly affect robot accuracy. Other factors which contribute directly to inaccuracies due to robot error include:

- robot geometry – the size and shape of each link between axes and the angular deviation between axes;
- stiffness effects, due to joint flexibility, bearing errors and limb bending;
- gearbox effects, such as transmission, backlash, hysteresis, reversal spikes and gear friction;
- servo errors;
- lack of secondary encoder data, or encoders mounted on the incorrect side of the gearbox;
- dynamic / loading effects;
- thermal expansions due to environmental changes or self-heating of the device; and
- vibrations.

The extent to which these factors contribute to overall robot inaccuracy depends on the robot architectures (cylindrical, spherical, delta, counterbalanced, parallelogram, SCARA and gantry). It is crucial to identify the dominant factors for each set-up so that appropriate steps can be taken to minimise errors. The interrelated effects of multiple factors can increase the magnitude of error.

For example, on a 2 m steel arm:

- a joint error of 0.03° leads to a tip error of over 1 mm
- a temperature change of 10 °C will lead to thermal expansion of 0.26 mm

Steps towards accuracy

Accuracy and repeatability can be stated globally for a particular robot, or as a sub-region of its working volume – tied to the application itself. The repeatability and accuracy of the specific region required for each application can be optimised in three ways:

1. Appropriate set-up, to ensure a good six degrees of freedom (DoF) tool frame and part frame definition.
2. Update joint offsets between axes to their true zero position.
3. Comprehensive calibration, to update DH parameters, joint compliance (bending) and other factors affecting accuracy.

Different forms of accuracy and repeatability

Typical industrial robots provide specification values under 100 µm. However, these refer to global static repeatability, which is the robot's ability to return to a stated point if the same path is used and the robot remains in a static position.

For many applications, other forms of accuracy and repeatability are critical.

- Dynamic repeatability: the robot's ability to trace the same path in the same direction, consistently describing the path on each run. This is important in applications where travel is critical, such as welding and machining.
- Multi-directional repeatability: the robot's ability to return to a stated position from (at least) two different directions. Repeatability in each individual direction can be at an acceptable level, but the difference between the two directions can be orders of magnitude larger due to backlash and hysteresis in the kinematic chain. This also affects the global accuracy of the robot as it is difficult to predict and compensate for.
- Absolute accuracy: the highest form of performance, desired in high-precision applications. It is defined by the repeatability of six DoF poses, and their proximity to an intended six DoF target within set tolerances.

These performance statistics are not stated on specific robot models, so robot performance must be evaluated in line with the specific requirements of each application:

- Is the target a point or a path?
- Will it be relative to another external axis, motion device or robot?
- Will the paths be repeated from one direction or will they alter from cycle to cycle?

Robot validation

Robots can be characterised in terms of their static and dynamic repeatability and absolute accuracy. For industrial robots, the ISO 9283 standard can be used to define methods of measurement, and calculation criteria for different accuracy requirements between robot architectures and models. These prescribed methods can be used in their entirety to fully document a robot's performance. More commonly, a subset of the operations are conducted to validate a robot to a certain level.

In both these cases, this provides a good baseline to compare robots of specific type, manufacturer, or model. However, it does not provide the true picture for application-specific validation. The characterisation of the robot may prove to be more or less capable for a particular application, once the other factors specific to the application are applied. For instance, if certain joints are exercised more than others, if the robot is subjected to environmental variation, if high payloads and excessive end effector force are required, or if only a subset of the working volume is required, the robot can be seen to over- or under-perform for that task.

Before commissioning any automation cell, the repeatability and accuracy requirements of each application need to be known and validated.

The positive impact of RCS products on automation

Renishaw's RCS range of portable ballbars and permanently installed probes and tool setters transforms the adoption and deployment of automation projects. The RCS L-90 is a single ballbar kit, designed to quickly attach to a variety of robots. It measures the robot's position and performance across a range of set-up and diagnostic tests. The RCS L-90 kit can be used to quickly and accurately find and set the tool centre point (TCP) and part frames. It can diagnose common issues such as single joint and global repeatability, backlash, path performance and volumetric performance.

The RCS T-90 ballbar kit applies the same principles using three ballbars. As well as diagnostics, this kit enables 3D path performance of a fully loaded robot, and identifies joint offsets, so that you can update the joints offsets of a 6-axis robot to their true zero positions.

Tactile probing and tool setting with the RCS P-series allows you to quickly create and find datum structures within your automation cells, simplifying programming and making offline programming practical. It automates the return of an automation cell to a known working state after a crash, thereby minimising downtime.

The combination of probe and tool setter allows a full definition of the part and tool frames. A five DoF end effector (for instance, a machining spindle) can be automatically calibrated, updating both position and orientation data.

Conclusion

The evolution of industrial robots is producing a new generation of models with additional performance potential. These robots will become indispensable for various high-accuracy applications such as precision assembly, laser welding, machining, precision coating, and 3D printing.

The accuracy of robots is influenced by multiple factors, and different robot architectures require specific steps to optimise robot accuracy; including precise set-up, comprehensive calibration, and joint offsets updated to their true zero positions.

Performance can be measured in terms of static repeatability, dynamic repeatability, multi-directional repeatability, and absolute accuracy, with application-specific validation being crucial.

Renishaw RCS products play a vital role in diagnosing and optimising robot performance. The RCS L-90 and RCS T-90 ballbar kits and the RCS P-series calibrated probing and tool setting kits provide automation, simplicity, precision and reliability where there are currently manual tests and checks.

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