

Improved Accuracy of Unguided Articulated Robots

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ABSTRACT

The effectiveness of serial link articulated robots in aerospace drilling and fastening is largely limited by positional accuracy. Unguided production robotic systems are practically limited to $\pm 0.5\text{mm}$, whereas the majority of aerospace applications call for tolerances in the $\pm 0.25\text{mm}$ range. The precision with which holes are placed on an aircraft structure is affected by two main criteria; the volumetric accuracy of the positioner, and how the system is affected when an external load is applied. Production use and testing of off-the-shelf robots has highlighted the major contributor to reduced stiffness and accuracy as being error ahead of the joint position feedback such as backlash and belt stretch. These factors affect the omni-directional repeatability, thus limiting accuracy, and also contribute to deflection of the tool point when process forces are applied. Drawing from common axis configuration in machine tool design, an industrial robot integrated with secondary encoders yields tighter control on axis position and increases system rigidity, thus creating a more repeatable system and, in turn, a system that can be compensated to high accuracies.

INTRODUCTION

Investment in aerospace factory automation is met with high performance expectations and low cost demands. Manufacturers wish to deploy systems that can be programmed offline without teaching using minimal operator intervention. Automating the assembly of aerospace structures, specifically drilling, countersinking, and inspection, using traditional

automotive-style articulated robots makes for a particularly attractive solution with unique design challenges. The articulated arm offers a large working envelope capable of reaching 6-degree of freedom (DOF) poses along highly curved surfaces and can navigate into tight spaces due to its compact design. Because robots are produced in high volume, they typically prove to be a much lower cost motion platform as compared to tailored positioning systems. And, within the last 5 to 10 years, significant mechanical and control improvements have made the articulated arm a viable option for lower accuracy (e.g. $\pm 0.75\text{mm}$) aerospace assembly processes.

The defense aerospace industry has been interested in the use of articulated arm robots in aerospace production operation for many years. This interest in the use of industrial robots has its roots in the successful implementation of industrial robots in automotive plants. The use of industrial articulated robots offers airframe manufacturers significant potential benefits in both cost and flexibility when employed for assembly and manufacturing tasks. Implementation of articulated-arm robotic drilling and inspection technology has the can significantly reduce production non-recurring costs, assembly span time and aircraft Unit Recurring Flyaway cost by reducing hole drilling time, improving hole quality and reducing the ergonomic challenges. A robotic drilling cell can also improve assembly line footprint requirements and drilling accessibility, contributing to span time reduction.

Typical drilling applications in defense aerospace have consisted of large gantry style drilling systems requiring

significant facility footprints and clear access to the product. The gantry monuments limit head and spindle accessibility to the product whereas with a robot often numerous spindles can be applied within a similar volume resulting in a reduced quantity of cells to reach full rate. In addition, stem-walls or columns are typically not required because the robots are able to reach up and out over the product during cycle and move away from the product when out of cycle for manual operations. When confronted with the high demands required for aerospace assembly however, the robot systems have typically not been able to meet customer requirements.

Fundamentally, currently available industrial robots are designed for lower tolerance, high-speed work such as palletizing, picking and placing, welding, etc. and they perform these tasks quite well. However, tailoring for these operations have presented difficulties. Because the links on the robot are serial, error from the first joint is carried to the second, and from the second to the third, and so on. This produces a cascading effect on the error which magnifies what may be a small displacement at the joint into a large displacement at the tool center point (TCP). For a typical 3 meter reach robot, this caps the positional accuracy to, at best, a global tolerance of $\pm 0.5\text{mm}$ which significantly limits the potential applications of the technology. Although systems for guiding the TCP to its location via external metrology are available, these often present line of sight and cycle time issues, as well as additional maintenance and cost burdens that are preferably avoided wherever possible. However, it should be noted that the guidance process is significantly streamlined if the base system is accurate and rigid, essentially getting to or very near the target position in its initial approach. The ultimate desire is to rely solely on the global accuracy of the motion platform. To that end, careful analysis of the sources of error as well as significant production experience have highlighted areas of significant accuracy loss which can effectively be eliminated by direct measurement using standard, integrated sensor technology. Implementing this technology in conjunction with an accurate, rigid multi-function process head enables the application of affordable automation to a much broader range of higher tolerance aerospace components.

MAIN SECTION

ANALYSIS OF MECHANICAL SYSTEM

In a drilling application, the accuracy in which a hole is placed relative to some coordinate reference is largely the function of two performance criteria; 1) The positional accuracy of the motion platform in free space, and 2) The ability of the motion platform to remain in position when external loads are applied (e.g. clamp pressure, drilling, etc.).

The pose of the TCP is obtained by driving the robot axes to a calculated angular position based on the

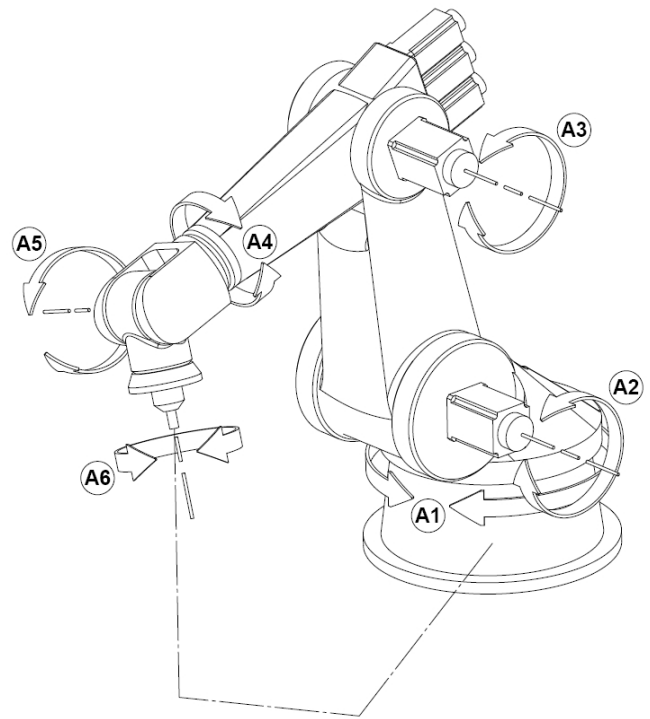


Figure 1. Typical serial link 6-axis robot

kinematic model of the arm (Figure 1). On a typical 3m reach arm, the nominal model, which is based on ideal link lengths, offsets, and rotations exhibits an accuracy of about ± 2 to 4mm within its working volume. Because the physical robot never matches the nominal model due to manufacturing and assembly tolerances, a unique higher order model can be developed to better describe each individual arm. This model can also include parameters for drooping affects from the masses of the links and payload and has been shown to achieve a positional accuracy of $\sim \pm 0.5\text{mm}$ in a restricted range. With any model, no matter how perfect, the ultimate TCP pose is a function of the 6 robot joints angles. The position feedback for each robot axis is located at their respective servo motors. Ahead of the feedback are numerous sources of error, such as backlash in gearing and u-joints, belt stretch, shaft twist, scaling error, etc. To further complicate, the wrist axes are often mechanically coupled, meaning movement of one affects the position of another, therefore a means for calculating for and correcting coupled axes must be implemented. Joints that are farther from the tool point have a more significant affect on error with the first axis being the worst as it is typically not actively preloaded nor loaded via gravity. Although the uni-directional repeatability of robots is generally good, omni-directional is significantly more substantial. Testing of omni-directional repeatability using a standard robot in typical working volumes has demonstrated magnitudes of up to 0.5mm . Poor repeatability can be attributed to uncertainty in the joint position. Because the system's accuracy can only be as good as it's repeatability, the best a standard system could ever achieve in ideal conditions is TP 0.5mm . Therefore, fundamental to system accuracy is knowing the position of each axis.