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# Design of a robotic orbital driller for assembling aircraft structures

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ABSTRACT

Orbital drilling is a machining process designed to drill holes with a double circular motion, added by a linear displacement in the direction of drilling. A cutting tool is rotating at high speed in an eccentric orbit and simultaneously moves towards the surface of the material to be drilled. The adjustable eccentricity plus the diameter of the tool defines the final diameter of the hole. Orbital drilling is a fatigueless process with good surface finish and burr-free when compared with conventional drilling processes. To implement this process, an automatic orbital drilling device has been designed and built as an end-effector of an industrial robot. The process of developing this device, its requirements, functions and tests are detailed in this paper, resulting in the construction of the EFORB (an acronym in Portuguese of Robotic Orbital Drilling End-effector). This paper presents the latest results with the final version of the system, including the development's integration with an industrial anthropomorphic robot. The results achieved show that the process requirements and tolerances are suitable for aeronautic applications.


## 1. Introduction

The aerospace industry is an important productive sector capable of absorbing new technologies in virtually all areas of human knowledge. According to [1], aircraft manufacturers invest millions of dollars every year in developing new products and processes, demanding new technologies from the market, especially those associated with the processes of aircraft manufacturing.

Among the various stages of the aircraft manufacture process, structural assembly is an activity that is time consuming, as pointed out by [2]. In the assembly of aircraft structures, all internal and external parts are fixed by solid rivets or fasteners, most of them installed manually. This manual process consumes up to 40% of the total production cost of an aircraft as shown by [3], mainly due to the sequential activities associated with this process. Such activities vary slightly in the complexity of implementation depending on the location; nevertheless they consist primarily of:

- Pre-assembling the parts.
- Location of the hole.
- Fine positioning of the drill.
- Drilling and countersinking.
- Hole calibration.
- Deburring and cleaning.
- Application of sealant.
- Riveting.
- Quality inspection.

The installation of a single union element (fastener) is preceded by a drilling operation, which must meet the requirements of form, finishing and position of the hole.

Innovations in the aviation industry tend to increase production capacity, production flexibility and cost reduction with improved quality assurance of the product, as discussed in the work of [1]. Automation of the riveting process contributes to reduction in the assembly time required, and drilling is a critical activity in this process. Much of the assembly processes involved in creating high-level structures (floor grids, lower and upper half-shells and barrels) use conventional manual drilling due to the high complexity of the parts to be processed.

Such manual drilling is frequently associated with risk of rework, reduction in the process capability range, and structural impairment, resulting in extra costs, as considered in [4]. The automation of aircraft assembly processes in the manufacture of both high- and low level structures requires the integration of different fields of knowledge to develop devices that reduce the assembly cycle time while maintaining optimum quality standards. The development of solutions that confer such savings of time and material in the drilling of holes with the precision and other quality characteristics required by the aircraft industry is an important engineering challenge today. Creatively exploiting new automation technologies to achieve production goals will advance productivity in the aviation sector.

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### 1.1. Review of robotic drilling

Industrial robotic applications are becoming widely used in the aerospace sector. Table 1 shows a synoptic analysis of the literature pertinent to drilling processes and the involvement of industrial robots therein.

Some papers listed in Table 1 consider the use of a specific driller produced by a particular manufacture and available on the market. Others discuss the development of entirely novel driller systems, and thus differences are marked. Only [3] details the use of an orbital drilling system available from a commercial vendor (Novator®), and focuses on analyzing the contact force and dislocations produced by the orbital driller under examination.

Standard robotic manipulators, on the one hand, provide high degrees of flexibility to enable functionality in large-volume processes, including those involving the manufacture of parts with complex geometries. This feature is discussed in all the papers listed in Table 1 (with the exception of [11]) which examine the use of only two step motors controlled by a PLC (Programmable Logic Controller).

On the other hand, however, this flexibility causes poor stiffness of the robotic arm. This relatively lesser rigidity affects the relationship between the end-effector and the work piece, making the drilling process susceptible to several types of nonconformities in the hole created, some of which can (and do) result in failure to meet the exacting requirements of the aeronautical industry, as discussed in Section 1.3.

Nevertheless, low degrees of mechanical stiffness in robotic arms could be compensated by special features fixtures, such as clamp systems or contact force control measures, as had been described in [8,7,2,4]. An interesting clamp system is shown in [3], which uses a rubber nose fixed by vacuum. The pressure force must be controlled during the entire drilling cycle in order to reduce the tangential forces' potential to spoil the hole quality (the sliding of the drilling tool on the surface during the operation can seriously degrade both the position and other characteristics of the hole), but the approach is worth attention.

Another drilling requirement is the required angular positioning of the drilling tool relative to the target surface. Control of this aspect of the drilling process is well described in [11], in which a trigonometric principle is applied to measure the deviation of the drilling device's angularity in meeting the target surface so as to promote the correct alignment of the tool. Ref. [9] also explore the flexibility characteristics of industrial robots relative to their performance in drilling operations, presenting a routine to keep the tool tip frame of the robot driller aligned with the surface. Ref. [5] details a system developed to find the normalization component vector, formed by an array of 4 laser range sensors and a vision system with 2 cameras. These devices are used to establish a virtual plane tangent to the surface of the work piece at the precise location of the desired hole and thereby ensure the angular consistency of the drilled hole.

A good review of the roles played by industrial robots in aerospace assembly applications is available in [7]. Most of the examples provided confirm that there is significant interest in the adoption of industrial robots in the industry's assembly lines, but the aerospace sector lags behind other sectors in the amount of robotic cell employed – certainly far below the levels prevailing in the automotive or packaging industries. The main challenge to be overcome in making increased use of industrial robots in aircraft assembly lines is the positioning accuracy required for these processes. This consideration is evaluated in [10], under the criteria and procedures of ISO 9283 (1998) norms. Their results highlighted the already known limitations of the industrial anthropomorphic robot, emphasis on poor absolute accuracy and good repeatability error, quantifying these errors with the use of a laser tracker, a laser interferometer, and telescopic ball bar instruments in assessing the positioning performance of ABB IRB series robot.

Also discussed in [5,6] were the limitations of absolute positioning accuracy of this type of robots (with 6 D.O.F.), emphasis on analysis pertinent to aircraft industry requirements. Both papers discussed solutions for aircraft component assembly and subassembly processes, their authors concluding the importance of an external metrological system to measure the relationship between the robot end-effector and the work piece.

In order to reduce the time required to programming the robot path, off-line programming is a good alternative. The procedure shown in [2] is applied in CNC (Computer Numerical Control) machinery, but it is suitable to industrial robot as well. Due to the high complex geometry of an aircraft part, off-line programming became a necessary tool to accomplish the task to automate the drilling process.

### 1.2. Analysis of the drilling operation

In any task involving drilling into a surface, common sense yields the expectation that this will be done by conventional means, using a twist drill. In fact, there are many references that emphasize the importance of the conventional drilling process in industrial production [8]. Some advantages of the conventional drilling process are: low cost, fast operation, wide availability of machines and tools, plus the well-established knowledge of the drilling process and its parameters. Disadvantages of the conventional drilling operation – inherent in the process – include burr formation and deformation of the hole's periphery. Even when the cutting parameters and the correct choice of the tool have been set, these effects occur, and they are prone to maximization when the cutting edge become dulled, as discussed in [12]. It is known that the central point of the drill has no speed relative to the drill itself. Because of this, the drilling stress at this point is at a maximum, resulting in several types of burr formation, circularity error and work material breakouts, as analyzed in [13].

The drilling process employing a conventional drill is a rough operation, resulting in the final diameter of the hole and its

**Table 1**
Synoptic analysis of the drilling process.

| Paper (year) | Contribution | Industrial robot | Drilling system | Metrology system |
|---|---|---|---|---|
| [5] (2002) | Drilling and fastening end-effector | KUKA KR350 | Uses | Laser rangefinders and CCD camera |
| [6] (2002) | Lay-out for automatic riveting system | Two virtual Tricept | Uses | Photogrammetry |
| [3] (2002) | Application of a commercial orbital drilling tool | ABB IRB 4400 | Uses | None |
| [7] (2007) | Automated assembly system | COMAU S2 | None | Laser seam finder |
| [8] (2007) | Force controller | ABB IRB 2400 | Develop | None |
| [4] (2010) | Drilling end-effector | KUKA model not provided | Develop | None |
| [9] (2011) | Explores task redundancy in drilling | ABB IRB140 | Uses | None |
| [2] (2011) | Off-line programming | CNC machine | Uses | None |
| [10] (2012) | Studies the positioning performance | ABB IRB1600 | None | Laser tracker, interferometer and telescoping ballbar |
| [11] (2012) | Normal adjustment system | PLC and step motor | Uses | Laser rangefinders |