COMPARATIVE STUDY BETWEEN TWO METHODS FOR PERPENDICULARITY CORRECTIONS IN ROBOTIC MANIPULATORS

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Abstract. *The aeronautic industries are researching automation technologies for the manufacturing process based on COTS (commercial off-the-shelf) industrial robots. The bottleneck of this research is the fact that the accuracy of the industrial robots does not meet the requirements of the aeronautic sector. Some works have developed the possibility to increase the accuracy of industrial robots based on either a vision system, a high volume measurement system or a customized design measurement system.*
An end-effector that performs multiple operations, such as drilling, sealing and fastening was developed in order to automate the assembly process of two circular fuselage barrels. To accomplish those tasks within tolerance, a vision system corrects the position and a perpendicularity measurement system measures angular deviations in order to ensure normality between the end-effector and the fuselage.
This work presents the integration of a perpendicularity measurement system with an industrial robot based on two different correction approaches: (1) the absolute method measures the angular deviation and sends a real variable to the robot in order to reorient the end-effector; (2) the incremental method checks if the end-effector meets the tolerances; if not, the perpendicularity measurement system sends a boolean variable to the robot to increment or decrement the actual orientation.

Keywords*: airplane manufacturing automation, industrial robots, null measurement method, absolute measurement method, incremental measurement method.*

1. INTRODUCTION

The industrial robots are frequently used and have been boosted by the automotive industry (Holland and Nof, 1999). However, traditionally, most of the assembly activities of an aircraft are performed manually, because the robots cannot reach the tolerances used on the aeronautic industries (Summers, 2005).

Typically, most part of the aircraft assembly activities are performed manually, sometimes by a customized gantry robot. According to Kihlman (2005), a gantry machine costs can reach 200 times the costs of an industrial robot.

Airplanes manufacturing automation by industrial robots has been studied by the main companies, for instance, the development of end effectors for the structures assembly processes by Dassault (Costa, 1996), Airbus (Kleebaur, 2006), Boeing (Devlieg and Feikert, 2008) and Embraer (Rangel, 2010). The prototypes developed in those papers present some solutions to the robot accuracy problem.

Vision systems are already used on robots to correct the linear positions (Hutchinson, Hager and Corke, 1996). But the orientation correction made by a single camera is not trivial, because, according to Meng and Zhuang (2007), is necessary a chess texture painted on the surface.

Mostly, vision systems increments or decrements the robot position based on a reference point previously read. To measure the absolute position of the last robot link is necessary a high volume measurement system. Kihlman and Loser (2003) use a Laser Tracker as a feedback measurement system for robots position while Summers (2005) uses a photogrammetric measurement system. Villani et al (2010) done a metrological evaluation of an industrial robot for aircraft structural assembly using an indoor GPS and a measurement system based on photogrammetry.

Cibiel and Prat (2006) and Devlieg and Feikert (2008) developed end-effectors with different perpendicularity measurement systems. They studied the drilling process and realized that is necessary to drive the robot to touch the fuselage to prevent chips formation between the fuselage plates and avoid vibrations. This touch procedure is named clamp and they used a mechanical systems control the touch force and adapt and measure the normality angular deviation on a fuselage surface.

The Brazilian aircraft industry is ranked third in the world market for commercial aircrafts, according to the last ABDI (2010) report. The manufacturing processes automation is a key factor for maintaining this position in the world aviation marked. It is essential for improving the quality of the product, reducing costs and production times.

Since from 2009, ITA (*Instituto Tecnológico de Aeronáutica*) has developing a project, named AME (*Automação da Montagem Estrutural*), about the automation of the fuselage assembly process using industrial robots, supported by FINEP (a Brazilian governmental agency) and by the Brazilian aeronautic industry (Furtado and Cabral, 2010).

The AME Project aims to develop national technology for the aircraft structure assembly processes automation and includes the design and construction of a new robot with different kinematics concepts for the fuselage align, the developing strategies for metrology and machining of holes and construction of a multifunctional end-effector for drilling, sealing and fastening named EFIP (Rangel, 2010).

EFIP, stands for *Efetuador de Furação e Insersor de Prendedores*, needs to be able to correct the linear and angular deviations and improve the industrial robot accuracy. The position measurement uses a vision system while the orientation measurement uses a customized solution. This work is about the integration of the EFIP perpendicularity measurement system with the robot and presents the results of a comparison between two different correction methods.

2. THE PERPENDICULARITY MEASUREMENT SYSTEM

It is important to measure and correct the angular deviation of EFIP relative to the fuselage surface in order to drill a hole that meets the tolerances of perpendicularity. Furtado, Villani and Sutério (2009) presents a design of a perpendicularity measurement system based on the studies of Cibiel and Prat (2006) and Devlieg and Feikert (2008) about the angular measurement system for robots end-effectors on a fuselage surface. This measurement system calibration and validation was presented by Furtado, Villani and Sutério (2010). Figure 1 (detail a) present the back side of the designed perpendicularity measurement system and detail b shows the front.

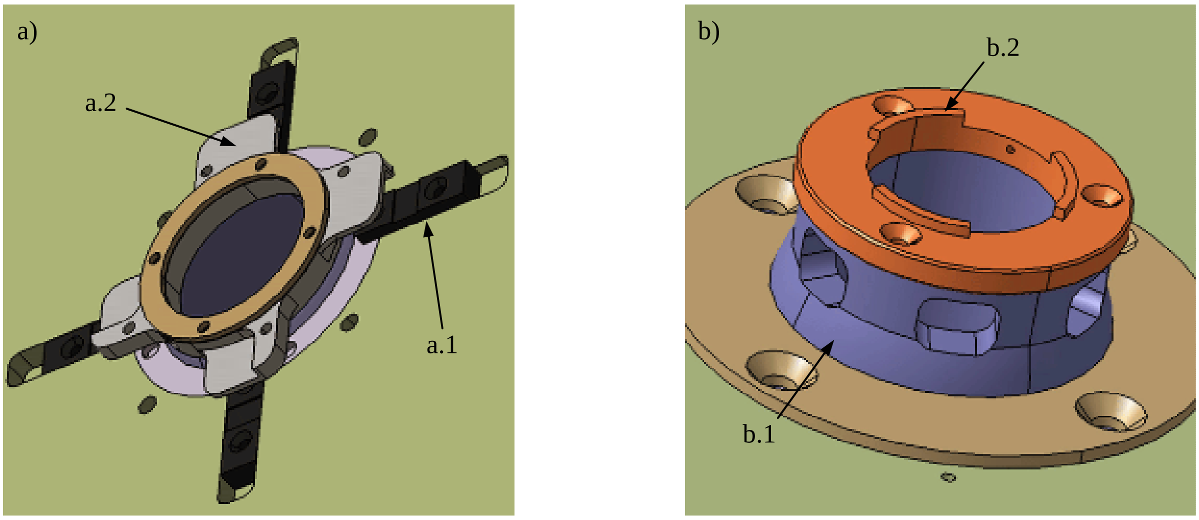

Figure 1 - Perpendicularity measurement system of EFIP (Furtado, Villani, Sutério, 2009).

In the Figure 1 there are four distance sensors (a.1) that measure the displacement of a customized radial spherical plain bearing (b.1) when the front part (b.2) touch the fuselage surface. The method of measurement chosen is based on the position measurement of a plate border (a.2) position by four sensors.

These sensors calculate the rotation of a plane, formed on the plate (a.2) surface, in the X and Z axes (α_X and α_Y). The angular measurement uncertainty is shown in Table 1. For details, see the paper published by Furtado, Villani and Sutério (2010).

Table 1 - Uncertainty of angular measurement.

Angles less than 1°		Angles less than 2°	
α_X	α_Y	α_X	α_Y
0,060°	0,046°	0,157°	0,180°

The tolerances of the aeronautic industry about the perpendicularity of the holes is about 0,5°. So, this measurement system fits to the tolerance needs, because the uncertain of angular measurements for angles less then 1° is about 10 times better than the tolerance.

The objective of this paper is present the conclusion of this project development with the integration of the measurement system and the robot based in two different orientation correction methods. To accomplish this main objective, some goals are listed below:

- Describe the methods of integration and correction;
- Develop the EFIP and the robot software;
- Run experiments;
- Analyze and discuss the results.

3. INTEGRATION AND CORRECTION APPROACHES

Two different approaches are proposed for integration between the robot and EFIP for correction of perpendicularity deviations: the absolute method and the null method. According to Doebelin (2004), the null method is more accurate and free from calibration, but is too slow to be used in application that changes the measurand values all the time. The maximum range that the perpendicularity system can measure with good accuracy is 2°.

3.1. The absolute method

When the measurement system touch the fuselage, the EFIP software calculates the angular deviation in X and Y axes. The value is send, by an OPC network, the angular value (real variable) to the robot, that reorient the end-effector to meets the tolerance. Figure 2 present the flowchart of this method.

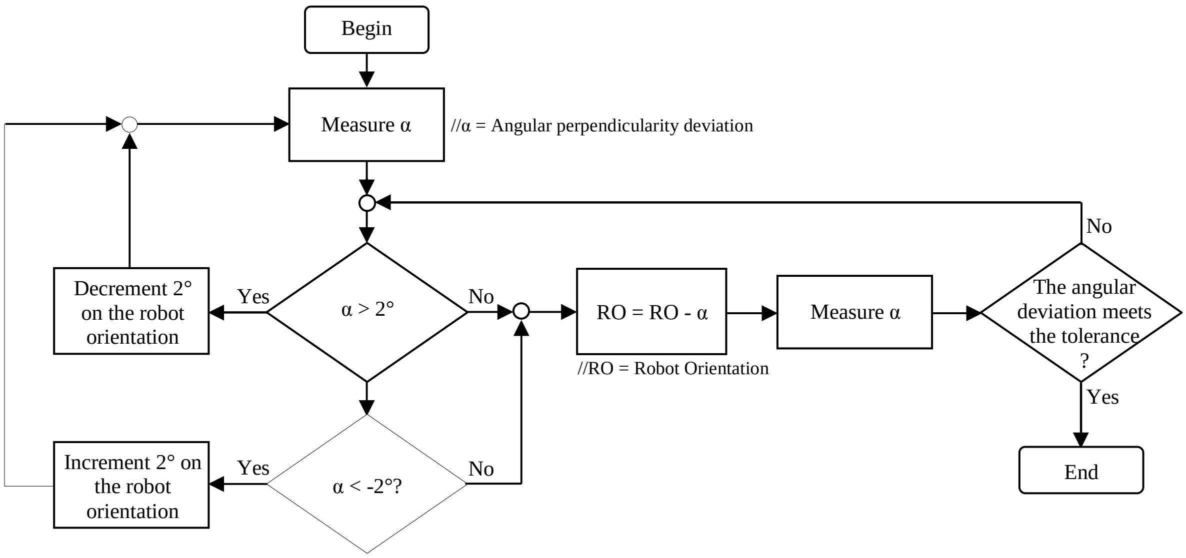

Figure 2 - Absolute correction method flowchart.

3.2. The null method

The null method is based on the increment of the robot original orientation if the angular perpendicularity deviation does not meet the tolerance. To start the orientation increment or decrement is necessary a boolean variable, different than absolute method that sends a real variable to the robot by an OPC network. A flowchart of this method is show in Figure 3.

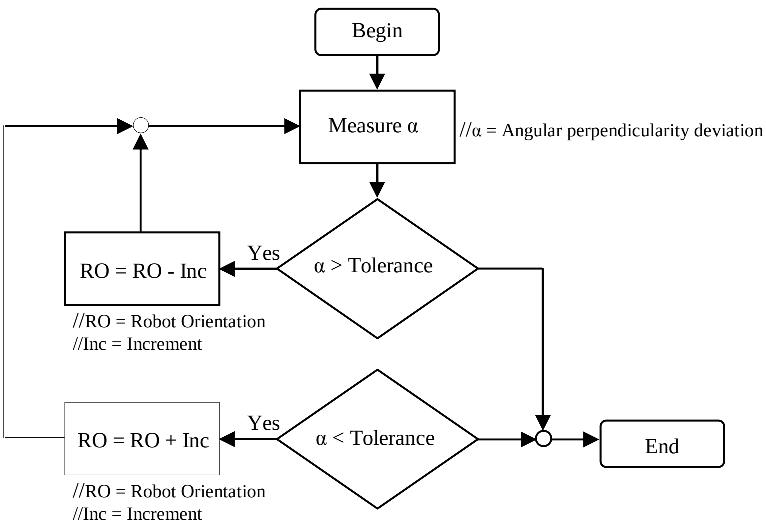

Figure 3 - Null correction method flowchart.

4. EXPERIMENTS AND DISCUSSION

From previous experiments, it was verified that generally, the errors of perpendicularity using the robot does not exceed 1° and rarely exceed 2°. Therefore, to evaluate the time and accuracy of the EFIP convergence, the robot was programmed with angular deviation of 2° (worst case) in several different configurations.

The figure shows a Cartesian system representing the X and Y axes of the EFIP plane and the Z axis that should be perpendicular to the fuselage.

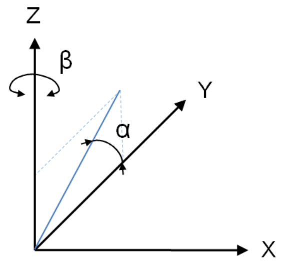

Figure 4 - Orientation configuration of the robot.

To generate different settings of the robot orientation, the angle α was set at 2° and the angle β, which represents a rotation around of the Z axis, was varied in steps of 45 °. With this criterion is possible eight different orientation of the robot, shown in Table 2. Two corrections were performed for each position of the Table 2, totaling 16 measurements for each method.

Table 2 - Orientation possibilities for the robot.

β	α_X	α_Y
0°	+2°	0°
45°	+2°	+2°
90°	0°	+2°
135°	-2°	+2°
180°	-2°	0°
225°	-2°	-2°
270°	0°	-2°
315°	+2°	-2°

4.1. Results of the absolute correction method

The following graphs represent time (horizontal) angle values (vertical). The tolerance used in this process is 0.3°. The results of the experiments is presented below by of graphs that show the value of the angle between the EFIP the table, whereas 0 ° represents EFIP totally perpendicular. These angles were measured every 100ms. Figure 5 and Figure 6 present the absolut correction method.

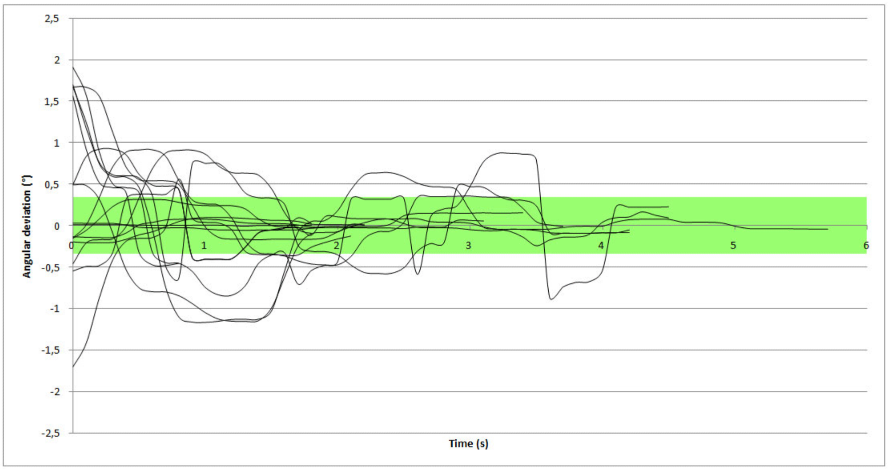

Figure 5 – Absolute correction method results (X axis).

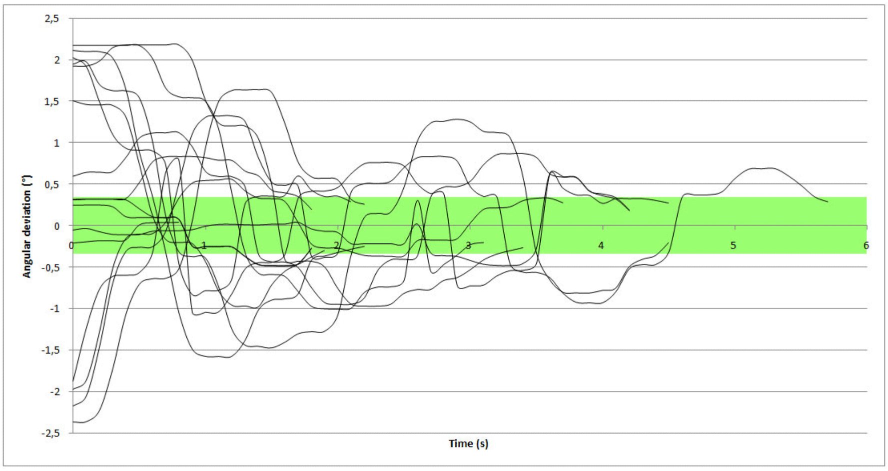

Figure 6 - Absolute correction method results (Y axis).

4.2. Results of the null correction method

Figure 7 and Figure 8 present the graph of convergence to tolerance done by the null correction method. The tolerance used in this process was also 0.3°.

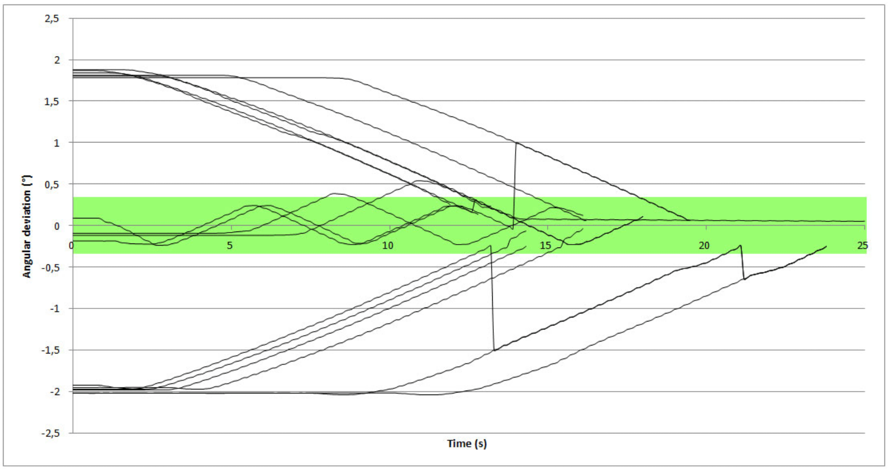

Figure 7 – Null correction method results (X axis).

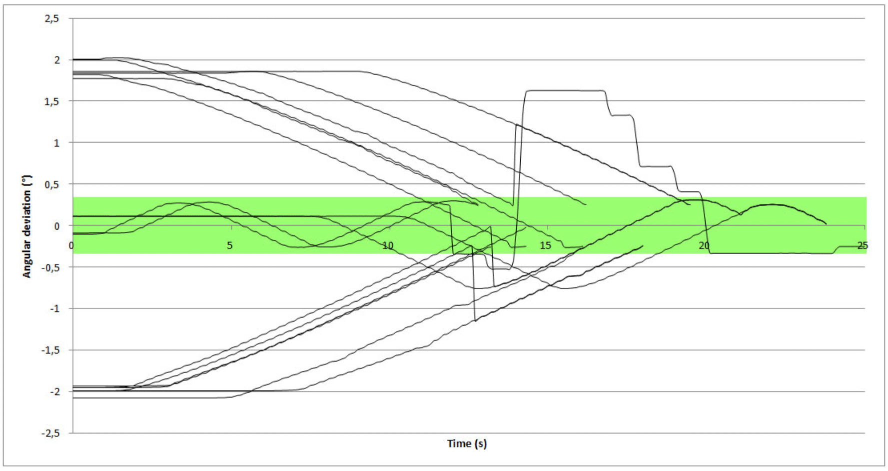

Figure 8 – Null correction method results (Y axis).

4.3. Discussion and methods comparison

Both methods proved satisfactory for convergence to the tolerance specified. However, absolute correction method did converge EFIP for perpendicularity in an average time of 3,5s, while incremental correction method made the correction around 18s.

According to Doebelin (2004), a longer time for correction was expected in null method. But five times long than the absolute method was unexpected.

It was noted a delay between EFIPsoftware and the robot software of about 4s when null method was used. One justification for this delay is that the null method must to be written continuously on the robot and that might have overloaded transmission of information across the network.

5. CONCLUSION

The perpendicularity measurement system can be integrated to an industrial robot and both proposed methods can be implemented in the EFIP controller. The absolute correction method is faster, however, incremental correction method tends to be more accurate.

Both methods were tested with angular deviation of about 2° in both axis X and Y. However, visually, these deviations are large and in a real production process would probably not be achieved. It is estimated that the largest angular EFIP that will have to correct is about 1° or less.

There was some delay in timing between the variables sent and received by the EFIP and the robot. With improvements in network devices between the two patch time could be decresed.

Based on the results and the objective to insert EFIP in a production process, it is assumed that the absolute correction method is the best way to meet the perpendicularity tolerance of the robot in relation to the fuselage, it is fastest (approximately 3,5s) and can converge to the prescribed tolerance of 0,3 °.

6. ACKNOWLEDGEMENTS

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