A ROBOTIC SYSTEM WITH 12 DOF FOR POSITIONING AND ORIENTATION OF LARGE STRUCTURES CONTROLLED BY CNC

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Abstract. *An unconventional robot named NIVA (NIVelamento Automático) are present in this paper. This robot are composed by 12 linear axis distributed in four towers with orthogonal movements. Each tower termination has a spherical joint connected in a large structure, and a kinematics improvement allows both position and orientation limited to 6 DOF. These movements have the objective of promote the alignment between two fuselage sections, one piece mounted in NIVA and the other in an industrial robot with a special end-effector to hold the aeronautical structure.*
The control of the dynamics of NIVA, position and velocity, is made by a CNC 840D, from SIEMENS, which is responsible to move the 12 linear axes simultaneously. The CNC technology is already used in other industrial segments like milling process and gantry robots. But the use in a bespoke robot with 12 DOF and kinematic restrictions to manipulate large structures is inedited.
The objective of this paper is introduce the technical requirements for NIVA operation and the layout created on the LAME (Laboratório de Automação da Montagem de Estruturas Aeronáuticas) laboratory to support the flatness process.)

Keywords*: Robot design, aeronautical manufacturing automation*

1. INTRODUCTION

The aeronautical manufacturing process has been researched by the main companies in the world. One example is the assemby process using robots to drilling. The original accuracy of the COTS (commercial of the shelf) robots is not good enough to assembly airplanes, but Costa (1996), Kihlman (2005), Kleebaur (2006), Devlieg and Feikert (2008) and Villani et al (2010) developed prototypes that present solutions for the robot accuracy problem.

In the steps of aircraft's manufacturing, one of the most susceptible to automation is the alignment and leveling sections of fuselage. According to Williams et al. (2000) the use of automated systems in this stage of construction can bring benefits that result in better competitiveness.

Conventional processes of fuselage alignment and leveling use jigs to ensure correct positioning of the sections during the assembly processes of an aircraft. The alignment and leveling of the fuselage sections occurs at the time that specific parts of jigs involved in the process are connected. This procedure is performed manually by operators that turn a threaded rod, moving the barrel up and down at each corner. It relies heavily on the operator expertise.

The positioning of the jigs requires much time, and this is one of the major reasons to automate this process and so significantly reducing the assembly time of an aircraft. Although increasing production speeds, the quality of the results of alignment and leveling process still was an impediment to the use of robotic systems. According to Summers (2005) the lack of positioning and orientation accuracy of the robots could be considered the main impediment to the use of robots in the aircraft industry.

This issue has been solved once large volume metrology systems have been integrated into robotic systems. Examples of these systems are the Laser Tracker and Laser Radar, both based on devices capable of sending and analyzing laser beam. Another example is the Indoor GPS system or iGPS that has similar functionality to the global positioning system by satellites, but applied for indoor environments. Finally, there are systems based on photogrammetry.

Recently companies specializing in process automation have been developing solutions for the aviation industry integrating large volume metrology systems. The company Automation Integration Technology (AIT) is positioned in the global market as a leading provider of turnkey solutions for the manufacture of aircraft. The AIT has projects in various stages of production of an aircraft, with emphasis on the leveling and alignment process, drilling and insertion of fasteners and wings assembly

AIT's solution to the alignment and leveling the fuselages is based on the use of individual electromechanical positioners. The drives of these positioners are made simultaneously by a system control with a dedicated graphical interface. To ensure the quality of alignment and leveling, the solution of the AIT is equipped with a measurement system consisting of an indoor GPS system and a laser tracker. Figure 1 shows a schematic of the ATI system implemented at Boeing. A photo of the real system can be seen in Figure 2.

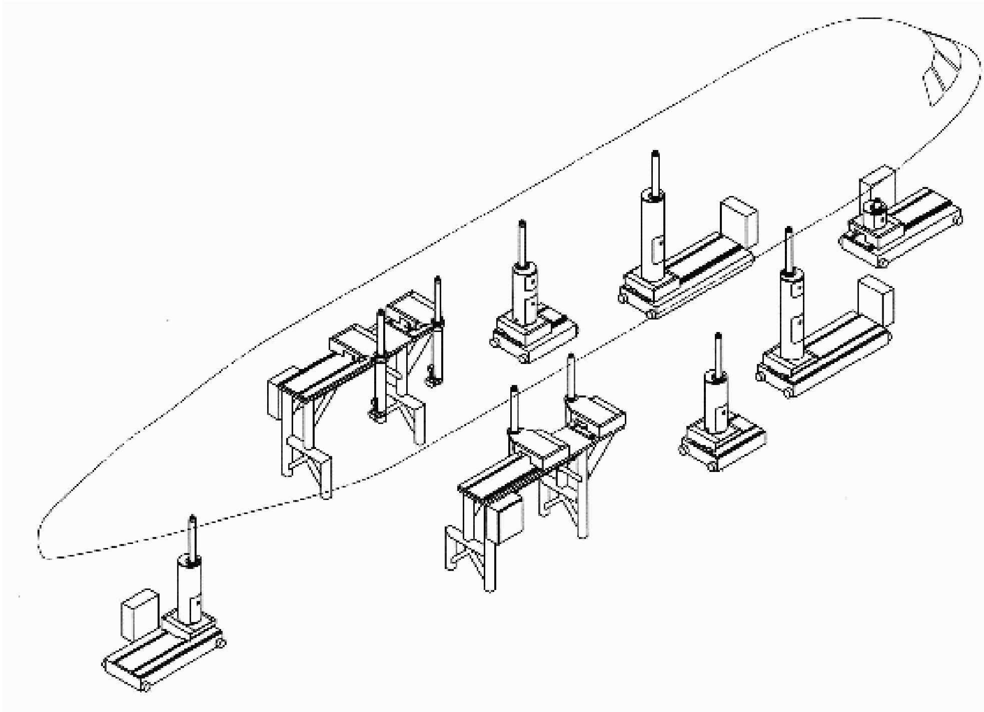

Figure 1 - Conceptual layout using independent positioners (WILLIAMS; CHALUPA; RAHHAL, 2000)

Figure 2 - The AIT solution implemented at Boeing (AIT, 2010)

Another company that excels in creating automated solutions for the aviation industry is the German Brötje Automation. Like AIT, Brötje use large volume metrology systems, specifically the Laser Tracker to ensure the quality of positioning made by the robots.

A differential of the Brötje also explored in the solution developed in this work is the use of a CNC command to control the position and velocity of the servo-motors used on the axes of positioners. Figure 3 presents the Brötje 's solution for the fuselages alignment and leveling process.

Figure 3 - The CNC controlled solution of Brötje Automation (Brötje, 2011)

Based on the available solutions on the market and weighing the strengths and weaknesses of each one, the LAME team of researchers responsible for this work, has developed a hybrid solution using a robot manipulator KUKA KR-500 and an unconventional robot with 12 DOF, called NIVA, which is the target of this work.

2. THE DESIGN APPROACH

This section describes the design method used for the NIVA project. The inputs of this method are the requirements and the output is a conceptual design. Table 1 presents al the project requirement.

Table 1 - NIVA requirements.

Requirements	Values
Support the fuselage and operator weight	800kg
Fuselage accuracy position about	0,1mm
Movement range on the horizontal plane (x,y)	250mm
Movement range on the vertical axis (z)	100mm
Translate and rotate the fuselage without deformation	

After the conceptual design method study, this chapter described, separately, the application of this method for the design of the mechanical system and the electronics and control system. At last, a discussion about the final product is presented.

2.1. Conceptual design method

The method described is based on a common design sequence, presented by Cross (2008). To organize the design, the methodology is divided into tree steps. The first organizes the goals, the second orders the functions and the last one presents possible solutions for the product development.

Step 1: Objective Tree

The Step 1 of the conceptual design method looks like an ordinary design process. It is necessary to know and organize the project objectives. According to Cross (2008), one possibility to identify all the objectives (primary and secondary) is to prepare the design objectives tree. As shown in Figure 4, a generic objective tree is a chart where the main design objective is deployed in several branches in order to assure that the customer needs are fully understood by the designers.

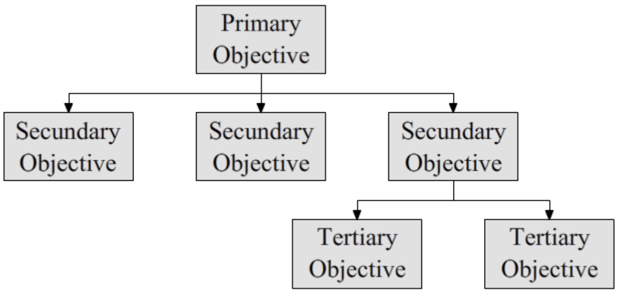

Figure 4 - Generic objective tree.

Step 2: Function Diagram

Then the product functionalities and the operation sequence must be described. A function diagram, as presented in Figure 5, could be used for this purpose (Cross, 2008). It is important to ensure that all of the objectives are met with the proposed functionalities for the product.

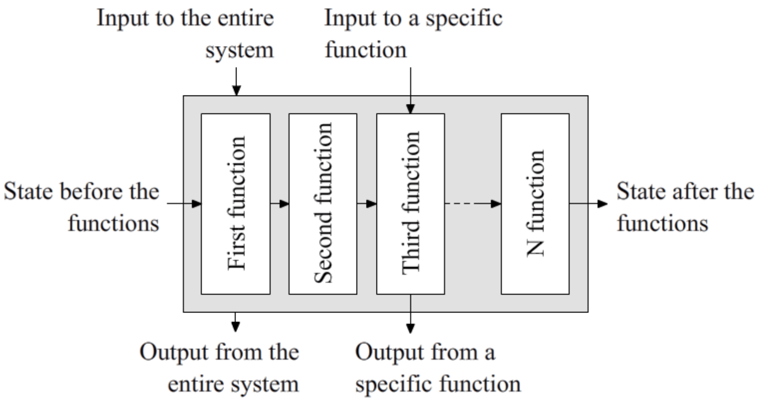

Figure 5 - Generic function diagram.

Step 3: Morphologic Chart

This last step presents some solutions for product under designing. First, a morphologic chart should be filled with technical possibilities and after select some potential good solutions for the product which is being designed (Cross, 2008). Table 2 shows a generic morphologic chart.

Table 2 - Generic morphologic chart.

Functions	Solutions		
1st Function	1st solution for the 1st function	2nd solution for the 1st function	nth solution for the 1st function
2nd Function	1st solution for the 2nd function	2nd solution for the 2nd function	nth solution for the 2nd function
kth Function	1st solution for the kth function	2nd solution for the kth function	nth solution for the kth function

2.2. Conceptual mechanical design

The conceptual mechanical design follows the three steps presented before.

Step 1: Mechanical Objective Tree

The objective tree of the mechanical design is based on the strengthened of the structure and the 6DOF to manipulate the fuselage in the positioning coordinates (X, Y and Z) and the orientation coordinates (R_X, R_Y and R_Z). The Figure 6 presents the organization of the goals.

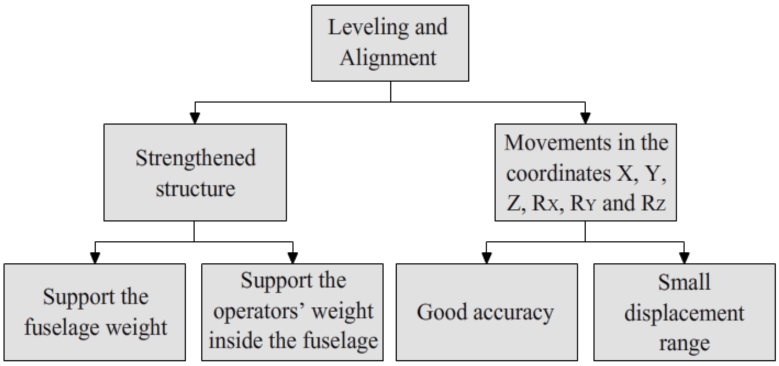

Figure 6 - Mechanical objective tree.

Step 2: Mechanical Function Diagram

As shown on the Figure 7, the functions and sequences of the mechanical design are presented. At first, the input of the system is the fuselage unleveled and unaligned. Next, the fuselage should be installed and fixed on the NIVA structure. After the fixation, it is necessary to measure strategic points of the fuselage to generate the center frame of leveling and alignment. Finally, the center point of the fuselage is compared to the center point of reference and the difference of position and orientation are sent to the NIVA mechanism to movement the fuselage.

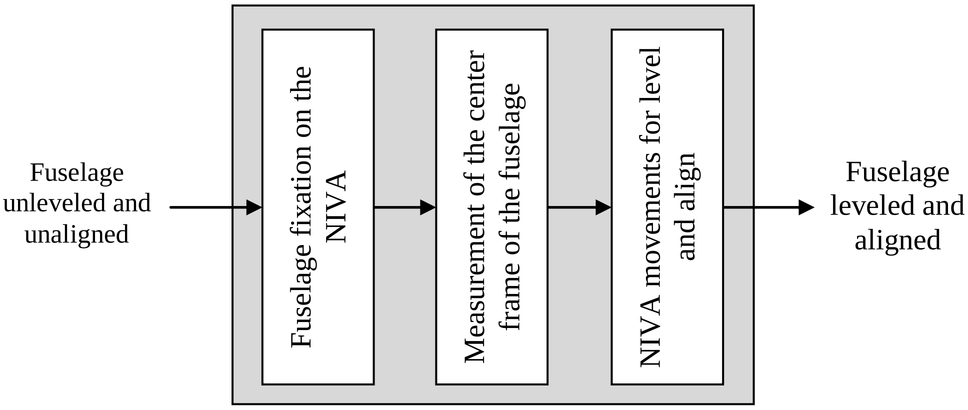

Figure 7 - Mechanical Function Diagram

Step 3: Mechanical Morphologic Chart

Some technical possibilities of mechanical design concepts are presents on Table 3. The functions described on the Figure 7 are presented on the first column.

Table 3 - Mechanical morphologic chart

Functions	Solutions			
Fuselage fixation on the NIVA	Suction cups	Solid support screwed on the fuselage	Seat shell	Magnetic fixation system
Measurement of the center frame of the fuselage	Indoor GPS measurement system	Photogrammetric measurement system	Interferometric measurement system	
NIVA movements for level and align	Individual towers with 3DOF each	Integrated movement of the mechanical system		

The criterion for choosing the solutions listed in Table 3 considers the system's flexibility, ease of installation, the possibility of application in the aeronautics industry and the viability of implementing the infrastructure of the ITA laboratory.

Fuselage fixation on the NIVA: Suction cups are a very good solution because is easy to assembly and disassembly the fuselage barrels at the NIVA and fits very well in industrial process. However, when the pneumatic energy is turned off, the fuselage can fall from the NIVA equipment. The magnetic fixation device needs a back iron support, because the fuselage is made by aluminum. The same problem of the suction cups appears, because when the electromagnetic energy is turned off, the fuselage will be not fixed anymore. The seat shell is a robust idea, but it is not flexible. So, the best kind of fuselage fixation is a support screwed at the fuselage. Maybe it is not the best way to fix a fuselage on NIVA in an industrial process, because is necessary a lot of time to do that. However, is the best way to fix the fuselage at the ITA laboratory, because the energy sources are turned off during the weekends.

Measurement of the center frame of the fuselage: According to Almeida et al (2008), each of those systems has different measurement time and accuracy. There is not a conclusive idea about witch measurement system fits better on the NIVA application. So this point is under studies.

NIVA movements for level and align: The individual tower meets the requirements of the aeronautical industry because follows the jigless trend, because it is a flexible systems, thus new models of product can be manufactured in the same manufacturing process.

2.3. Conceptual electrical and control design

The conceptual electrical and control design are described below.

Step 1: Electrical and control Objective Tree

The main objective of the electrical system is to control the servomotors of at least four towers with 3DOF each. Therefore, it will be necessary to control 12 axes simultaneously to not to deform the fuselage barrel. It is also important network connection to the measurement system and the rest of the manufacturing process.

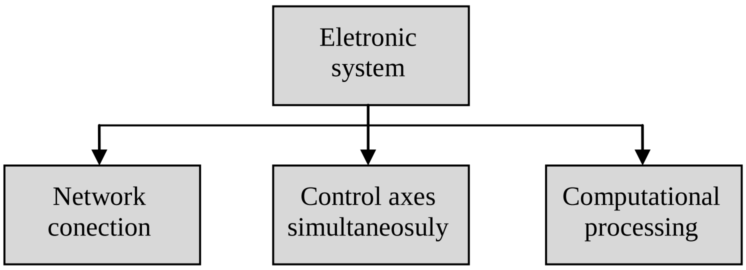

Figure 8 – Electrical and control objective tree.

Step 2: Electrical and control Function Diagram

The most important task of the electrical and control system is control 12 axes simultaneously. To do that, is necessary to have a computational processing that generates the trajectory of each single servomotor using the deviations of position and orientation of the central frame of the fuselage barrel.

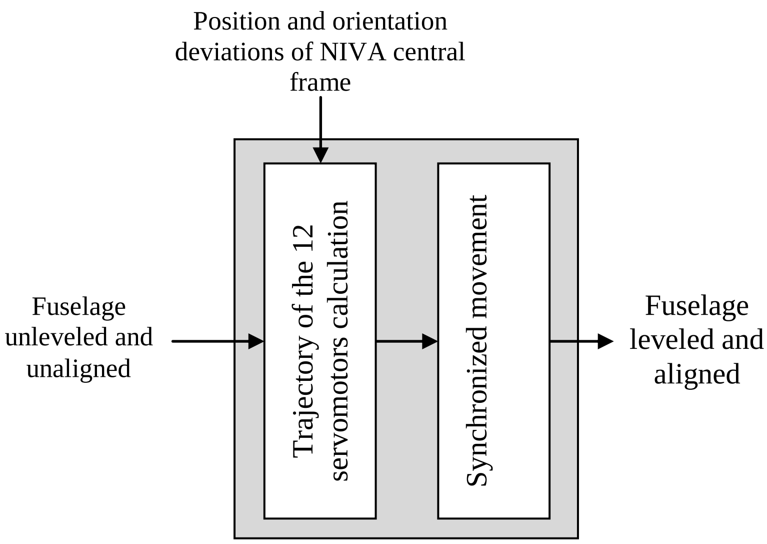

Figure 9 - Electrical and control Function Diagram

Step 3: Electrical and control Morphologic Chart

The electrical and control technical possibilities are presents on Table 4. The functions described on the Figure 9 are presented on the first column.

Table 4 - Electrical and control morphologic chart

Functions	Solutions		
Trajectory of the 12 servomotors calculation	Read the position and orientation and calculate the matrixes out of the controller and send just the 12 servomotors position	Read the position and orientation in the controller and movement the 12 servomotors position	
Synchronized movement	Step-Motor with a controller with 48 fast outputs	CNC	Individual motion drives with a synchronism

Trajectory of the 12 servomotors calculation: To create a robust control system, the position of the 12 needs to be calculated in the controller. This choice allows the development of a jog movement for manual operations.

Synchronized movement: Step-Motors are not so fast and have a limited torque. It is hard to ensure the synchronism of 12 individual motion drives. So, an easy and robust way to control 12 servomotors is a CNC. That is an interesting use of the CNC, which is generally used for machining centers, not in robots.

2.4. Final product conception discussion

After the morphologic chart elaboration (Table 3 and Table 4) was possible to determinate the best set of solution for the NIVA that meets the requirement.

The use of individual towers allows the application of the NIVA in different size of fuselage barrels and the CNC and implemented in this case gives more robustness to the process, and allows the simultaneous control of 12 individual axes. Figure 10 presents a schematic draw of NIVA design.

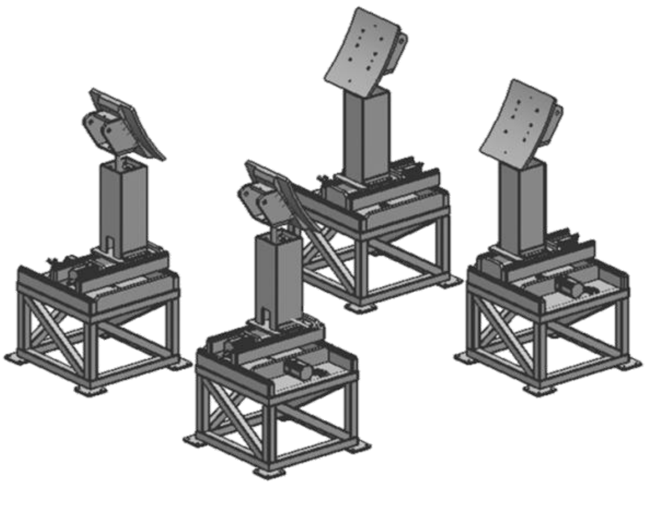

Figure 10 - NIVA schematic design.

3. CONCLUSIONS

The proposal to develop a non conventional robot for leveling and alignment of the fuselage barrels had a final product for flexible manufacturing processes.

It was observed that the configuration of the robot using four independent towers equipped with 3 DOF each, meets the requirements for movements of the automatic process for fuselages leveling and alignment. The strokes of each axes were sufficient to meet the maximum deviations of position and orientation.

As for using a CNC to control the robot, it has proved extremely effective, since it allowed simultaneous control of the 12 servomotors without the need to develop dedicated control systems to this application.

From the perspective of the controller's development for robotic manipulators, this project presents a migration of technology of CNCs that are consolidated in the manufacturing of machining centers and other types of industrial machinery. Figure 11 shown the actual status of this project with a fuselage barrel controlled by a SIEMENS 840D CNC.

Figure 11 - NIVA photography.

4. ACKNOWLEDGEMENTS

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