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Analysis of the indoor GPS system as feedback for the robotic alignment of fuselages using laser radar measurements as comparison

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ABSTRACT

The alignment of aircraft fuselages in the aerospace sector is currently done either manually or by complex, expensive automated systems. The manual process introduces a significant production delay and the automated systems are purpose-built and have limited flexibility, apart from its financial drawback. This work proposes a low-cost, high-flexibility system and, as part of it, evaluates the performance of a Rotary-Laser Automatic Theodolite (R-LAT) as a feedback source for the adaptive robot control of an anthropomorphic manipulator. In the proposed solution the robot carries a fuselage barrel and aligns it with respect to a second barrel. A high accuracy, frequency-modulated laser equipment is used to generate the reference system for the procedure. The measurements of the R-LAT are then verified with the frequency-modulated laser equipment in order to determine the linear and angular alignment tolerances achieved by the robot/R-LAT closed loop in a predefined work envelope. A throughout, step-by-step analysis of the measuring procedure is carried out to allow the recognition of error sources and thus the determination of an optimized method. These results identify the operation boundaries of the R-LAT within the process and yield its best configuration for the intended purpose. Using the EN ISO 9283 robot evaluation standard, the closed loop system was found to attain the nominal position with an average accuracy of 0.38 mm and 0.01°, contrasting with an average accuracy of 4.53 mm and 0.21° when the robot was operating in an open loop configuration.

1. Introduction

The ever-growing need to improve manufacturing processes has led to an increase, in recent years, in the number of automation solutions employed to assemble aircraft structural elements [1]. The work described herein is part of the activities being carried at the Aircraft Structure Assembly Automation Laboratory (ASAA Lab). An outcome of a partnership between the Aeronautics Institute of Technology (ITA) and the Brazilian aerospace sector, the ASAA Lab is developing an automated process for the assembly of aircraft fuselages.

This process is constituted of two main steps: the leveling and alignment of the fuselage barrels and the drilling and riveting procedures that join the barrels together. This paper is related to the first step, depicted in Fig. 1. It presents an analysis of a Rotary-Laser Automatic Theodolite (R-LAT), term coined by Muelaner et al. [2], as a feedback source for an industrial manipulator during the leveling and alignment process, having a frequency-modulated laser equipment as reference.

Currently, the alignment process of two barrels is done either manually or by complex, expensive automated systems. The manual procedure to assemble the structures of a plane, nose to aft fuselage, takes an average of 5 days [17] and introduces a significant production cycle time. An automated alignment shortens this time to a few minutes but current alternatives are high cost, dedicated systems with low-flexibility and limited possibilities of reuse. This work proposes the use of industrial manipulators in the alignment of fuselages given the fact that they offer good repeatability, modularity, flexibility of use and low cost if compared to systems such as gantry type robots. Nonetheless, they inherently lack two important characteristics needed for aerospace applications: absolute accuracy and stiffness [3]. In order to overcome these limitations, metrological feedbacks have been suggested to improve their spatial accuracy [4].

The contribution of this article lies in the implementation (Patent US61/286,295—2010, [5]) and evaluation of a closed loop fuselage alignment method using industrial robots. While the technologies involved in the implementation are not particularly

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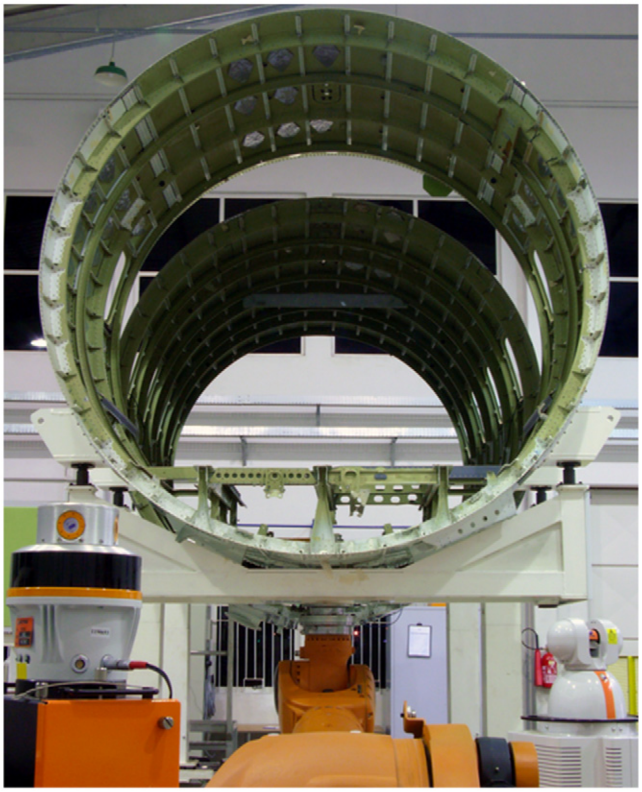

Fig. 1. Fuselage alignment at the ASAA Lab.

new nor their individual development is claimed by the authors, their combination and application to this industrial manufacturing context presents relevant novelty. Furthermore, no assessment of the performance of the equipment for this purpose can be found on the literature. The results of this work will guide the aerospace industry in the use of industrial manipulators for assembly processes as well as provide it with a reference to evaluate the performance of other systems targeted at this issue.

This paper is organized as follows: Section 2 presents a brief literature review of the current industrial robot usage in the aerospace sector and the development of large-volume metrology systems; Section 3 describes the experimental setup as proposed; Section 4 presents an analysis of the collected data; and Section 5 presents the work conclusions with a brief overview of future improvements.

2. Background

2.1. Related work

2.1.1. Robots in the aerospace sector

In the past decades, automation solutions, in particular industrial robots, have been widely used in the automotive industry [6,7]. They have been largely employed in welding and pick-and-place operations. On the other hand, only more recently the aerospace industry has started to adopt the solutions and potential benefits brought by automation, and has faced difficulties in implementing pre-existent technology. Kihlman [8] extensively discusses the current capability of industrial robots versus the new requirements for their use in aircraft automation. In aircraft assembly, parts require positional accuracy in the order of ± 0.20 mm, roughly a tenth of what those robots can deliver. Therefore, in order to benefit from their low cost, flexible automation, some sort of correction/compensation mechanism becomes imperative to allow the use of industrial manipulators in aircraft assembly.

Summers [9] presents a series of tests that demonstrate the incapability of standard industrial robots to meet the requirements of a high accuracy procedure, and describes the development of a photogrammetry-based adaptive control process to accurately position singular or co-operating robots within a large working envelope.

In another work, Kihlman and Loser [10] present the need to not only achieve an acceptable absolute accuracy but also to avoid deflection. The article presents a laser interferometry and photogrammetry based metrology solution to detect and compensate for deflection.

2.1.2. Present state of the art for large-volume metrology systems

Current non-contact metrology systems are mainly based on one of two technologies: laser and photogrammetry. In the laser category, two main products are the Nikon^{TM} indoor GPS (iGPS) R-LAT and the Nikon^{TM} Laser Radar system (LR), both being large volume metrology systems. While the iGPS is a tracking mechanism, the LR offers a much higher measuring accuracy ($\sim$10x) and is thus suitable for assessing the performance of the iGPS, though it can only perform static measurements.

Muelaner et al. [11] present a detailed description of the iGPS and its network setup, and reports an uncertainty of 1 mm at a 95% confidence level for a basic iGPS system compared with a network of laser tracker measurements. However, the literature is scarce in comparisons between the iGPS and LR systems, especially if comparisons are restricted to the aerospace domain.

In a previous work from the ASAA Lab, Villani et al. [12] present independent performance evaluations of industrial robots in the aircraft assembly process using the iGPS and the Nikon^{TM} K-610 photogrammetric device. Results from the iGPS system were at a quality level considerably lower than expected and motivated further investigation described in the present study.

Jayaweera and Webb [13] propose an alignment method applied to fuselage panels based on non-contact metrology-assisted industrial robots. They assessed a robot error of 0.515 mm for a 300 mm distance measurement.

Marguet and Ribere [14] present the measurement-assisted assembly based on laser tracker as a way to drastically reduce assembly time in both fuselage-to-fuselage and fuselage-to-wing junctions.

2.2. Equipment overview

A brief overview of the operating principles of the equipment involved in the experiment is provided below.

2.2.1. The iGPS

The iGPS is an R-LAT comprised of sensors and a transmitter network. A sensor consists of two collinear sensing elements, and its position is defined in spherical coordinates (elevation, azimuth and range). Each transmitter emits a LED pulse and also has a rotating head that sweeps the measurement volume with fanned lasers at 40 Hz. Since the lasers are fanned, the upper sensing element will receive the two signals at a different rate if compared to the lower element, as shown in Fig. 2 (left). This difference can be used to calculate the elevation of a sensor relative to a transmitter. Because of this, sensors must be used in a vertical alignment. The azimuth is calculated through the time difference between the LED pulse and the midpoint between the two laser fans, as shown in Fig. 2 (middle).

Considering Fig. 2 (right), one may notice that with a single transmitter the range coordinate of a sensor is undetermined.