

Structural Quality Inspection Based on a RGB-D Sensor: Supporting Manual-to-Automated Assembly Operations

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ABSTRACT

The assembly and manufacture of aerospace structures, in particular legacy products, relies in many cases on the skill, or rather the craftsmanship, of a human operator. Compounded by low volume rates, the implementation of a fully automated production facility may not be cost effective. A more efficient solution may be a mixture of both manual and automated operations but herein lies an issue of human error when stepping through the build from a manual operation to an automated one. Hence the requirement for an advanced automated assembly system to contain functionality for inline structural quality checking. Machine vision, used most extensively in manufacturing, is an obvious choice, but existing solutions tend to be application specific with a closed software development architecture.

Here we address these issues, presenting a robust solution for structural quality inspection using a low cost RGB-D sensor (Asus Xtion Pro Live) and open source libraries for point cloud analysis and processing. The system checks the quality of manually assembled sub-components before automated robot controlled operations are undertaken.

CITATION: Maiolino, P., Woolley, R., Popov, A., and Ratchev, S., "Structural Quality Inspection Based on a RGB-D Sensor: Supporting Manual-to-Automated Assembly Operations," *SAE Int. J. Mater. Manf.* 9(1):2016, doi:10.4271/2015-01-2499.

INTRODUCTION

Assembly and manufacture of aerospace structures requires the execution of a number of ergonomically complex operations, such as detailed assembly, sealant dispensing in restricted access areas, shimming, fettling, etc. Operations of this nature, particularly in legacy products, rely heavily on the skill, or rather craftsmanship, of a human operator. Certainly some of these processes can be carried out by a suitably designed robotic assembly cell, but in most cases the cost associated with such bespoke tooling does not prove to be cost effective. A more efficient solution to a particular problem may be a mixture of both manual and automated operations but herein lies an issue of human error when stepping through the build from manual operation to an automated one.

To ensure any automated process is carried out effectively after a manual operation (potentially subject to human error), an in-line structural quality inspection system is required that has the ability to confirm all the assembly's sub-components are mounted within design tolerances. Quality inspection could of course be performed by a trained operator [1], but again this is subject to potential human errors. Moreover, an automated system affords a higher consistency and bandwidth with a Boolean 'go' or 'no-go' decision.

Certainly, machine vision has been used widely in manufacturing and production for inspection tasks, in a number of applications [2]. Indeed the state of the art presents various solutions that use different techniques (both 2D than 3D) such as monocular vision [3], CCD cameras [4] or laser range imaging [5]

The solution proposed in this paper takes advantage of relatively new sensor technology that utilizes structured light [6]. One distinct advantage of this type of sensor is its low cost, allowing for high deployment density. A data rich manufacturing environment provided by sensors of this nature is a key enabling feature of the future cyber physical systems that would be part of an Industry 4.0 SMART factory [7]. Indeed it is foreseen that advances in computer vision capabilities will be accelerated with the use of low cost RGB-D sensors and the open implementation of visual algorithms [8].

SYSTEM OVERVIEW

The considered application scenario is the automated dispensing of sealant in the assembly process of aircraft parts. It is a necessity that the exposed interface between sub-components and the main part require sealant to protect the interface from ingress. As a reference part, it is used the representative geometry of a trailing edge rib bracket with an example sub-component. Figure 1 shows the bracket with the example subcomponent mounted in both the correct and incorrect orientation (although this is arbitrary for the purposes of this

test). Typically the next operation after sub-component assembly would be the application of sealant. For an automated sealant process a structural quality inspection must take place.

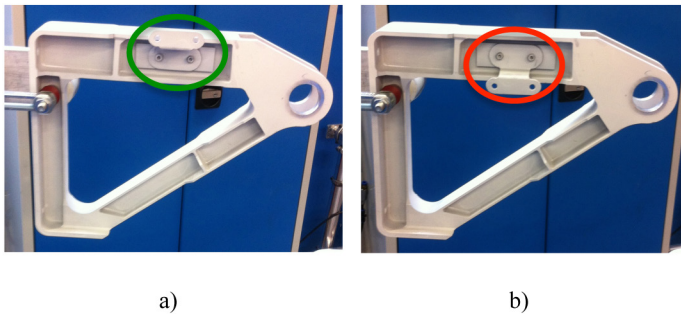


Figure 1. The generic trailing edge rib bracket used for the development of the inspection system with the example sub-components mounted in the a) 'correct' and b) 'in-correct' orientation.

The assembly is held in a test fixture that can accommodate a number of parts from the same component family (see Figure 2). Location was repeatable to $\pm 2\text{mm}$ in the plane of the fixture. The laboratory environment provides a suitable visual noise level to challenge the RGB-D sensor.

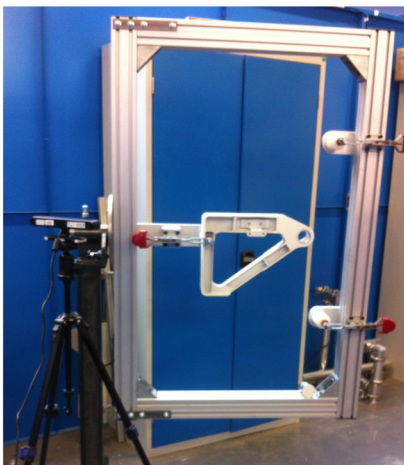


Figure 2. The fixture frame that holds the generic trailing edge rib bracket and the viewing position of the Asus Xtion Pro Live.

Figure 3 shows how the sensor is positioned relative to the fixture frame and the robot. This position ensures a good number of detection points describing the bracket and the subcomponent in question. As reported in [9] the depth image resolution of the sensor is inversely proportional with the distance between the object and the sensor and the point cloud density, defined as the number of the points per unit area, will decrease with increasing distance of the objects' surface from the sensor (it is inversely proportional to squared distance from sensor). This is due to the fact that while the number of points remains constant the area is proportional to the square distance from the sensor. The position angle has been selected in order to have a 2.5 D view of the object thus aiding the recognition algorithms.

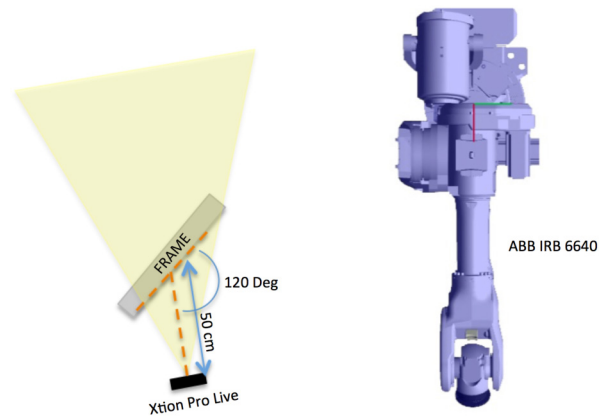


Figure 3. Top View of the scenario setup: On the right the sealant dispensing robot (ABB IRB 6640), on the left the fixture frame that holds the brackets and relative position of the RGB-D sensor.

RGB-D Sensor: The Asus Xtion Pro Live

A low cost RGB-D sensor (ASUS Xtion PRO LIVE) has been employed for the developmental inspection system. RGB-D sensors provide color information as well as the estimated depth for each pixel. Industrialized sensors using a similar type of structured light exist [10] but our goal is to take advantage of the new low cost consumer RGB-D sensors and of the community developing supporting software.

The sensor technology is based on structured light [6,9] (originally developed by PrimeSense) the sensor projects an IR-light pattern on the scene, the light returns, distorted, according to the position of the objects in the scene. Various algorithms are used to triangulate and extract 3D information from the CMOS image sensor. Table 1 presents the technical specifications of the Asus Xtion Pro Live, for a comparison of sensor types the reader is directed to [11,12], where the authors note that the future development and exploitation of these types of sensors lies in the development of advanced and robust algorithms rather than the refinement and cost increase of the sensors themselves.

Table 1. The Asus Xtion Pro Live technical specifications [8]

Metric	Asus Xtion Pro Live
Price	~150 USD
Power Consumption	<2.5 W
Field of View	58°H; 45°V; 70°D
Sensor	RGB, Depth and Microphone
Depth Image Size	VGA (640 × 480) 30 fps; QVGA (320 × 240) 60 fps
OS support	Win 32/64 XP, Vista, 7; Linux Ubuntu 10.10: X86, 32/64 bit, Android
Programming Language	C++/C# (Windows); C++ (Linux); Java
Interface	USB2.0

Point Cloud Libraries

The Point Cloud Library (or PCL) is an open source project [13] for 2D/3D image and point cloud processing released under the terms of the 3-clause BSD license and is open source software. PCL is a