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ROBOTIC LASER-ULTRASONIC INSPECTION OF COMPOSITES

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ABSTRACT. In laser-ultrasonics for inspecting composites, the beams are usually directed onto the part with a computer controlled scanning mirror. This approach has sensitivity limitations when the surface is very shiny (mold facing surfaces). This limitation is eliminated by controlling the direction of the laser beams with an articulated robot, its trajectory being determined from the CAD of the part or its surface mapping from a 3D laser scanner. The scanning mirror is eliminated. We are reporting here successful implementation on a 6-axis robot.

Keywords: Laser-ultrasonic, Laser-based Ultrasound, Ultrasonics, Composite Inspection, Robotic Inspection, Robot
PACS: 43.35.Sx, 43.38.Zp, 43.35.Cg

INTRODUCTION

Laser-ultrasonics is by now a well known technique for inspecting composite materials and is particularly efficient for parts with a complex shape. Generation and detection beams are usually directed onto the part surface with a 2-axis computer controlled scanning mirror assembly (including one or 2 mirrors). Several implementations of this approach are known and are reviewed in the next section. This approach has however some limitation when the surface is very shiny, which is often the case of the surface facing the mold. In this case, light from the detection laser scattered at an angle is very weak and sensitivity is consequently reduced. This limitation is eliminated when the detection light beam is directed essentially normal to the surface, which can be performed by robotic control of the beam direction. In this case, the robot trajectory is determined from the Computer-Aided-Design (CAD) of the part or its surface mapping from a 3D laser scanner. We are reporting below an implementation in which the scanning mirror is eliminated and the head coupling the generation beam, the detection beam and collected light is made very light in order to have minimum inertia to be moved and rotated rapidly by the robot.

PREVIOUS LASER-ULTRASONIC IMPLEMENTATIONS

We will review first several implementations which have been developed for inspecting polymer matrix composites. All the known systems use a Carbon Dioxide Transversally-Excited Atmospheric Pressure Laser (CO_2-TEA) as generation laser. The emission wavelength of this laser at 10.6 μm is partially or totally absorbed by the layer at the surface of the composite (epoxy resin, other resin or paint), which provides a constraining effect for the generated stress and minimizes potential damage. Further, the spot size on the surface being a few mm (typically 5mm), this provide the piston-like source which easily allows inspecting complex shape parts independently of the direction of the laser beam. The generation beam is also made collinear with the detection beam and generally comes from a Nd-YAG long pulse laser at the wavelength of 1.06 μm. This laser is very stable in frequency and is made by amplifying a high stability and monolithic cw laser. Both beams are reflected by a computer-controlled scanning mirror which allows raster scanning the inspected part. Scattered light, which carries the ultrasonic information as a frequency modulation, is received by the same mirror and then sent onto the interferometer (confocal Fabry-Perot or photorefractive interferometer). The interferometer produces a demodulated signal which is finally processed for plotting ultrasonic C-scan and B-scans of the inspected part.

Figure 1 shows the earliest laser-ultrasonic composite inspection system developed 15-20 years ago for Aerospatiale and Dassault Aviation by UltraOptec Inc. and the National Research Council of Canada (NRC). This system is still being in use in France after some upgrading [1,2]. In Figure 1, only the generation unit which encloses the CO_2 generation laser is shown, the detection laser and interferometer which are coupled with long optical fibers (40 meters possible) being remotely located and not shown. In this system the stand-off distance has been designed to be between 1.2 m and 3 m and the scanning mirror has a large size for collecting a significant amount of the scattered light (elliptical size 41cm x 21cm).

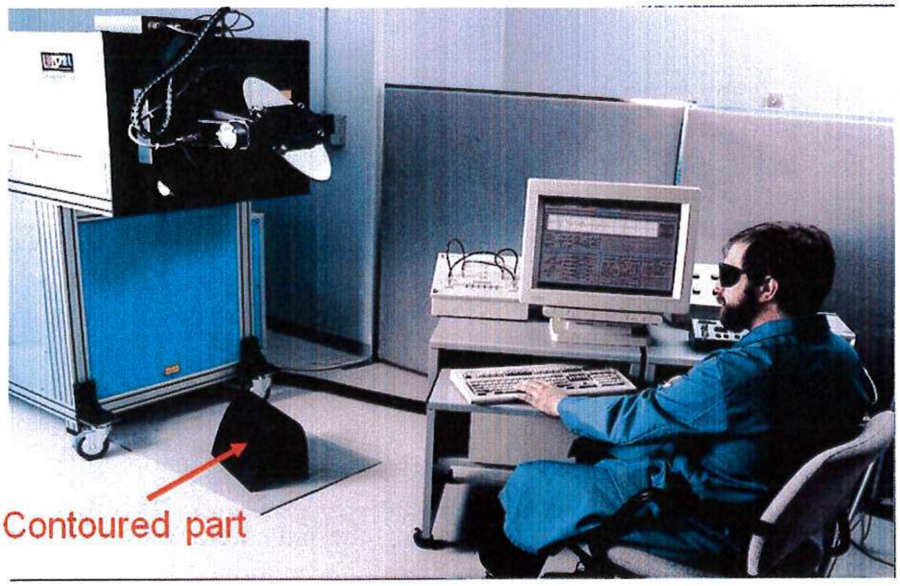

FIGURE 1. View of the first laser-ultrasonic system developed for composite inspection (generation unit only shown) showing the scanning mirror and the inspected contoured part located on the floor.

Another implementation made later for the US Air Force is sketched in Figure 2a [3]. Essentially the same unit as described above with its scanning mirror was mounted at the end of the vertical arm of a gantry robot. The enveloped of the gantry was such that the indexing of the generation unit allows inspecting a large part such as the wing of a jet fighter. Figure 2b shows the generation unit with its scanning mirror in front of an inspected part on its carriage. Systems based on similar gantry implementation with mirror scanning are being used by the Lockheed Martin Company for inspecting composite parts in a production environment [4].

Another recent implementation developed by Tecnar Automation and NRC, made specifically for inspecting large fuselage parts made by automatic fiber placement, is shown in figure 3a-b. In this configuration, the scanning head having a scanning mirror of size similar as the systems described above is mounted at the end of a long cantilever anchored to the plant floor by a pivot. The CO_2 laser is located on top of this pivot and directly coupled to the scanning head. The fuselage part rests on a carriage and is inserted through the cantilever beam, as shown in Figure 3a. The optical scanner has the configuration shown in Figure 1 and 2b and allows scanning around 360° and about ± 30°, so a large area of the cylindrical barrel can be inspected from a given location of the inspection head. As shown in Figure 3a, an additional rotational degree of freedom of the scanning head around a vertical axis is provided for scanning more easily stiffeners and the cockpit area, which does not have a cylindrical shape.

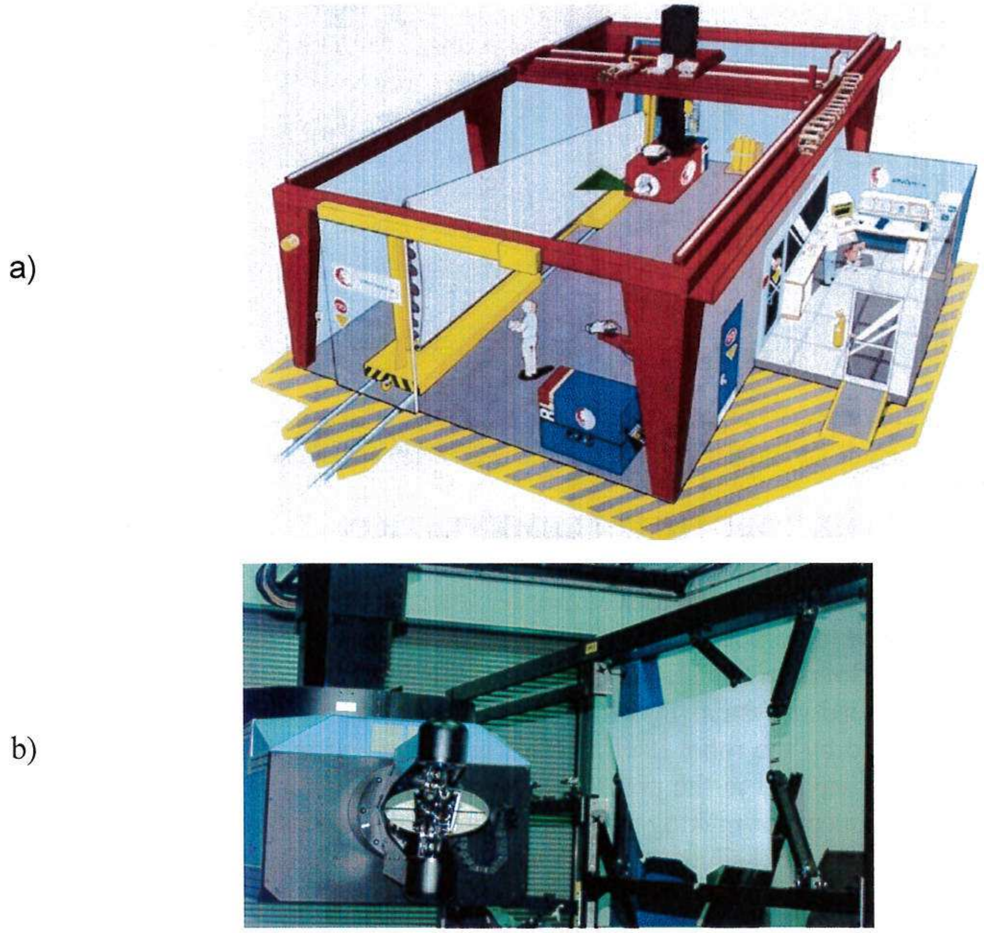

FIGURE 2a-b: View of the laser-ultrasonic system built for the US Air Force and installed at the McClellan Air Force base, Sacramento, CA, but now dismantled, a: sketch of implementation, b: generation unit with optical scanner in front an inspected part on its carriage.

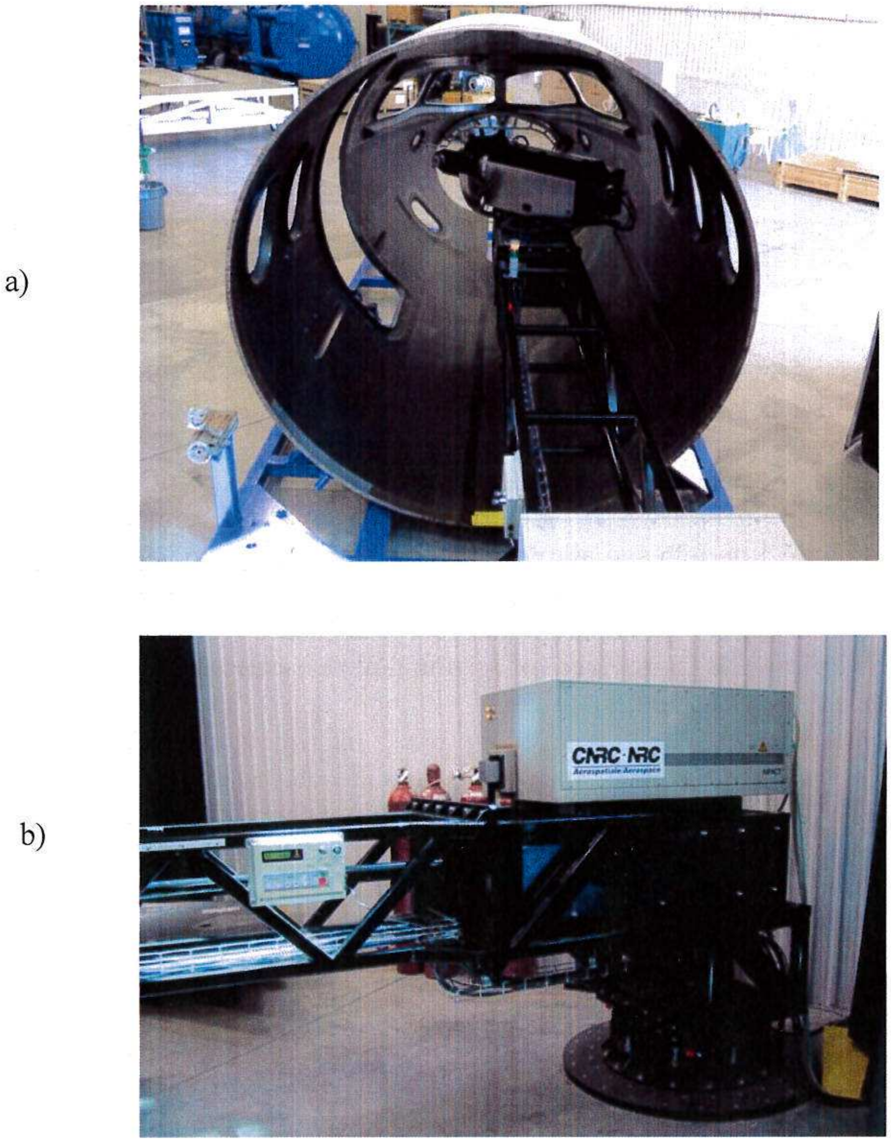

FIGURE 3a-b. View of the system developed for large fuselage composite inspection, a: inspection head at the end of the cantilever inside the barrel, b: CO2 generation laser on top of cantilever beam pivot.

DESCRIPTION OF THE ROBOTIC IMPLEMENTATION

Although it is possible to consider an implementation in which an inspection head with a scanning mirror assembly is mounted on an articulated robot, as the system developed by iPhoton Solutions and Tecnatom for EADS and installed in France [7], we have implemented instead a system in which the scanning mirror is eliminated and the whole scan is performed by the robot itself. In this implementation, the stand-off distance can be quite reduced compared to the previous ones since the robot permits to follow the part contour. The key aspect for making this implementation successful has been to design the scanning head as light as possible, in such a way that its inertia is reduced and the head can be moved sufficiently fast. In the implementation shown in Figure 4a-b, the stand-off is 15cm and the weight of the head is less than 1kg. A 6-axis Denso robot with an overall arm length of 77cm and maximum composite speed of 7.6m/s has been used for demonstrating this first completely robotic implementation. As shown in Figure 4a-b, optical fibers are used for coupling the detection beam and the collected light to the generation laser and interferometer, respectively, as in previous implementations. The CO_2 laser generation beam is coupled by an articulated arm, which is a well know technique for transmitting CO_2 laser beams for medical and industrial applications, since fiber coupling for high energy or lengths over a couple meters has never been shown practically feasible at 10.6 μm [8].

In this implementation the beams are sent essentially normal to the surface. This has the benefit to allow collecting more scattered light, particularly the often strong component, which is specularly reflected. This increases sensitivity up to the point where noise is dominated by laser noise. By using known schemes which allow laser fluctuations cancellation, such as using a photorefractive interferometer or a special version of a dual channel confocal Fabry-Perot [9], the threshold at which there is no further benefit of collecting more light is moved even higher. Therefore, the strong reflection of shiny surfaces that have been in contact with the mold can be fully exploited to get very high sensitivity.

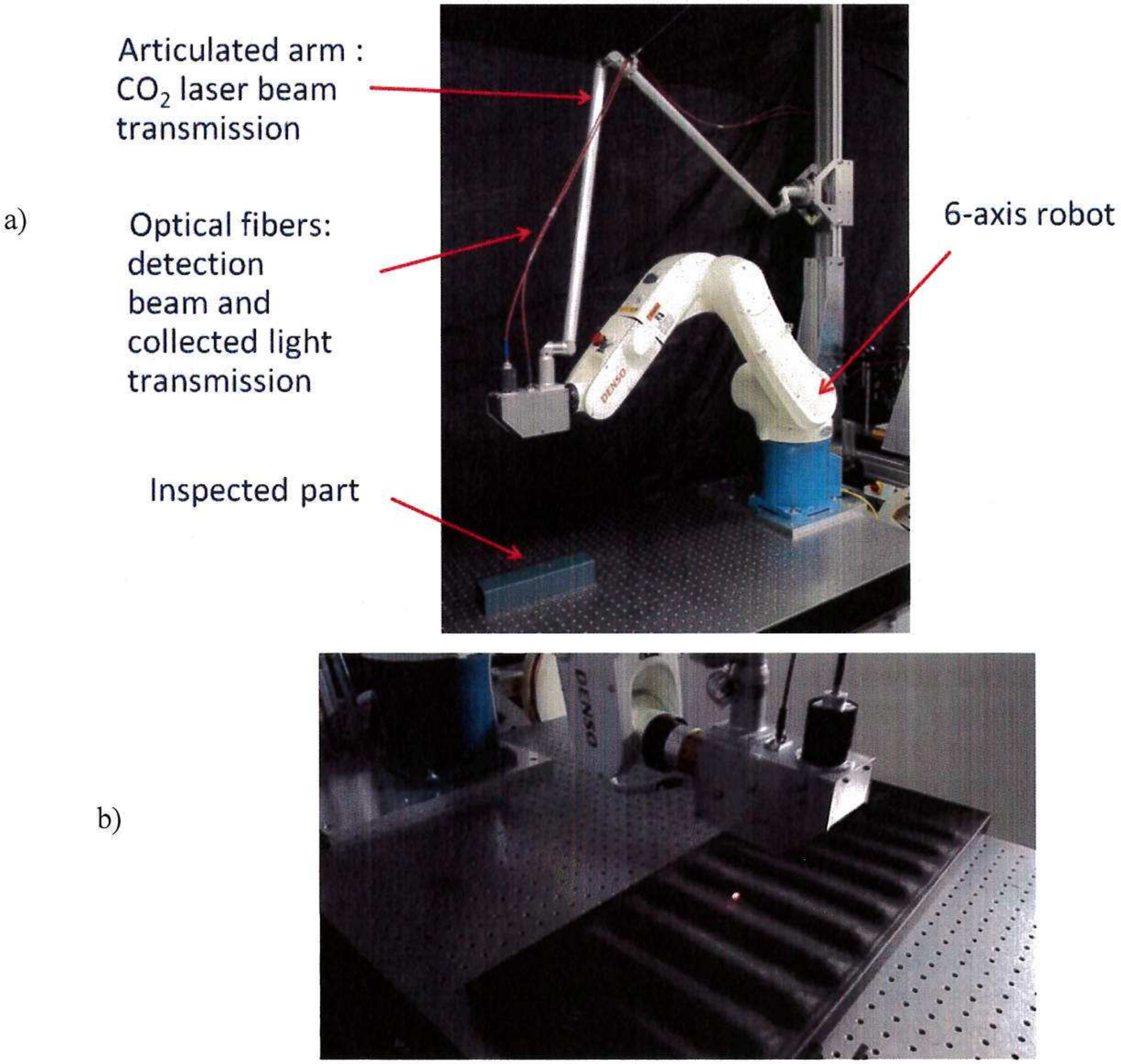

FIGURE 4a-b. View of the reported robotic implementation, a: view of the robot with inspection head and coupling means for generation and detection, b: closer view of the inspection head above a sinusoidal part being scanned (the large size CO_2 laser which is like the one shown in Figure 3b is not shown).

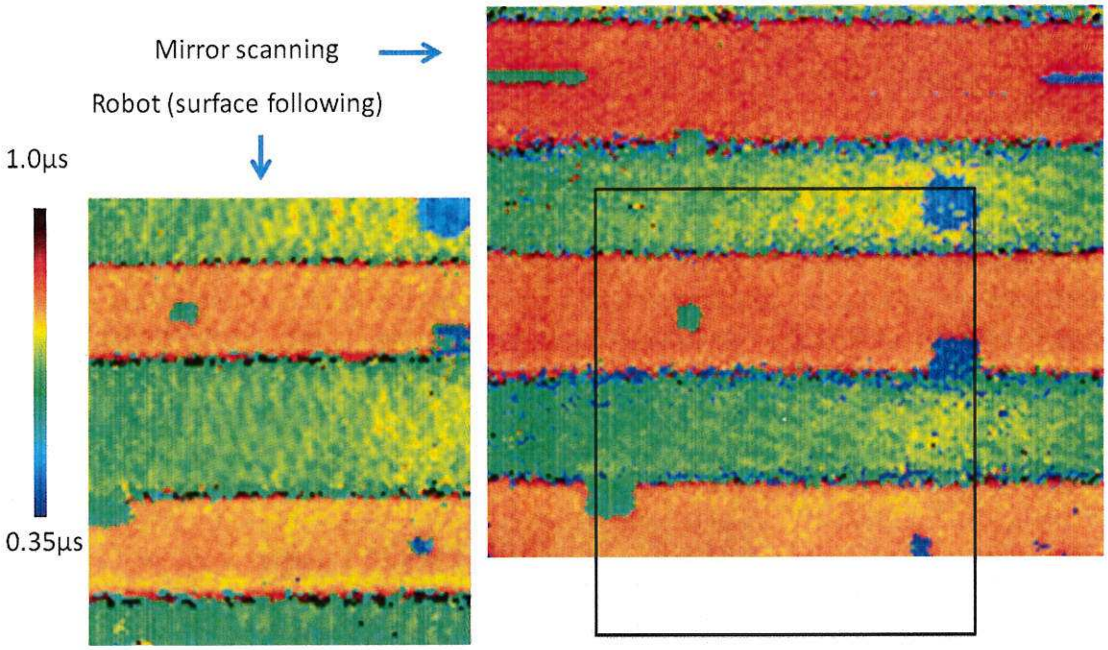

FIGURE 5. Comparison of a C-scans of the sinusoidal part made with the robot system and with a system with scanning mirror (system shown in Figure 3a-b). The rectangle in the C-scan at right obtained with mirror scanning indicates the zone that was scanned with the robot.

RESULTS

The system was tested on various parts with complex shapes, such as the ones shown in Figure 4a-b (U-shape part with corner radii of about 5mm and sinusoidal part). In this first demonstration of such a robotic implementation concept, the surface of the part was analytically modeled. The coordinate values provided by the model were then fed to the robot controller to control the head trajectory. In an on-going development, description of the surface of part is being provided by an optical scanner. For other parts, for which a CAD model is available, the CAD model can be used as input for programming the trajectory. Figure 5 shows the comparison between the C-scan of part of a sinusoidal component with implanted defects obtained with the robot configuration and the one obtained with the more traditional mirror scanning configuration (actually, the system shown in Figure 3a-b designed for big barrel structures). Thickness variations and implanted flaws are seen in the two scans, which are found in good agreement.

CONCLUSION

In conclusion, we have demonstrated a novel implementation of laser-ultrasonics for inspecting composite materials that uses a robot programmed to follow the surface contour of the part. In this implementation, there is no scanning mirror and adequate inspection speed is obtained by having a sufficiently light inspection head, such that it does not limit robot speed and acceleration. A benefit of this implementation is the higher sensitivity at detection by higher collection of light. In particular, this implementation circumvents the difficulty occurring with parts with very shiny surfaces, composites as well as metals, for which light collection becomes rapidly insufficient for beams incidence away from normal, resulting in poor sensitivity of the traditional mirror scanning implementation. Such an implementation is also very flexible and should be more convenient for inspecting parts of very complex geometry than any other.

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