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Synchronism system for generating ultrasonic images of complex geometry pieces using industrial robots

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Abstract

This paper presents a synchronism system that has been designed to facilitate the generation of ultrasonic images of pieces with complex geometry through the use of industrial robots. Modern robotic manipulators and, more specifically, industrial robotic arms integrated with server computers, sensors and actuators have revolutionized the way automated non-destructive testing is performed. Currently there are commercial industrial robots that have the precision, speed and repetitiveness in their movements that make them suitable for use in numerous non-destructive testing inspections whose designs are carried out by small and medium sized specialized companies. Automatic ultrasonic inspection of complex parts remains one of the most difficult challenges according to the specific and increasingly exigent demands of the markets. The closed configuration of these complex robotic arms makes it difficult to maintain adequate synchronism between the movement of the robot and the acquisition of the data, making it difficult to generate ultrasonic images consistent with the geometry of the part. This is a serious problem in the inspection of aerospace components where high quality is necessary to assess the condition of the inspected component. In this paper, we present an autonomous independent external system that provides control signals to synchronize the ultrasound system with the robot trajectories without needing to access its position in real time. A methodology to obtain the timing pattern for a given part inspected with a given robotic system will also be presented here.

KEYWORDS: Industrial robots; ultrasounds; complex geometry; synchronism, photogrammetry.

1. Introduction

Industrial inspection robots allow to enhance and extended the safety of industrial assets, and is an important part of NDE 4.0. For this reason is important developing reliable automated solutions to speed up repetitive inspection of large numbers of components in the production chain [1]. Robotic manipulators have typically been operated by predefined tool-paths generated through offline path-planning software applications. Although, several aspect need improved and the conjunction of different approach as photogrammetry could be a valuable tools [2].
The following study aims to locate the positioning of a photographic or video camera through the use of the photogrammetric technique; which "is the art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena" [3]. The concept of photogrammetry is: "measure on photos". If we work with a photo we can obtain information in the first instance of the geometry of the object, that is, two-dimensional information. If we work with two photos, in the area common to them (overlapping area), we can have stereoscopic vision, in other words, three-dimensional information. Basically, it is a 3D coordinate measurement technique, which uses photography or other remote sensing systems together with topographical reference points on the ground, as the fundamental means of measurement. This up growing tool is being used in several industries as Cultural Heritage [4], among others.
For this specific case of study presented, photogrammetry has been applied to automated ultrasonic inspection systems using industrial robotic arms, in order to find the location where each frame was captured, then through interpolation, we were able to point out the exact coordinates of the robotic arm during the inspections.

2. Methodology

2.1 Previous tests

During the first stages of this study, a series of videos of the robotic arm were taken, recorded with a high-speed camera (PROMON U750 model) at Tecnitest facilities. A curved element with a regular surface became inspected. The information obtained consisted in several videos, from which a series of frames were extracted thanks to VLC Media Player, subsequently the frames were exported to the photogrammetric software, Agisoft Metashape to carry out different tests, in order to verify the system's viability.

Figure 1. Industrial inspection held at Tecnitest with the high-speed camera attached on the lower side of the robotic arm.

It is important to stress out that all frames must have equal properties (*f* number, exposure time, ISO, focal length) in order to function. Once they have been imported to the software, the workflow starts by aligning in a virtual 3D space by using common points: the result is known as a dense point cloud. From this cloud, the software can continue the workflow interpolating more points to create a dense point cloud, however, this process is not relevant for the purpose of these studies, since the interest lies in the position and inclination of the high-speed camera (hence the robotic arm location) while the video was being recorded. The images obtained from the videos made at Tecnitest did not allow for the generation of a consistent photogrammetry of the documented surface and therefore the location of the camera during the process. The main reason was the quality of the image extracted from the videos, due to the reduced distance between the camera and the object, leaving a large part of the images out of focus. This does not allow having enough points in common between the different frames so that Agisoft Metashape software can align all of them to generate the model. Likewise, direct illumination of the surface is also detrimental to the correlation of points, and it is advisable for an optimal shot to use an overhead light that evenly illuminates the entire object.

2.2 Experimental methods

In view of the results, the next step was to perform an experimental method at the Institute for Physical and Information Technologies "Leonardo Torres Quevedo", ITEFI from the Spanish National Research Council (CSIC). For that purpose different technologies were used to check which technique was the most suitable. Within the tests conducted, objects with similar characteristics to the ones inspected were documented, to later mirror the new method at Tecnitest facilities. During this whole process, homogeneous lighting was maintained and a high camera depth of field (*f* 10 or higher) was used, in order to facilitate the points alignment.

2.2.1 High-speed camera method

The tests were carried out with the high-speed camera previously used at Tecnitest, the PROMON U750 series, a high-speed camera system that records directly to the PC via USB3. The capture was carried out by sweeping the surface horizontally, from left to right, ensuring the images obtained were overlapped so that the software became capable of detecting the coincident points between them thus generating an accurate photogrammetric model. The system for extracting the frames was through the use of the VLC Media Player, by using a filter that allowed converting the video into frames, choosing the rate of recording. However, this automatization can be executed by other tools such as Python or Matlab. After several tests, it was concluded that the photogrammetric models were not consistent, due to the trembling movements while holding the camera, which caused the resulting frames to be out of focus and therefore the software failed to align. As a result, it was decided to set the camera in an automatic Cartesian system to be able to systematize the tests.

2.2.2 Automatic Cartesian system method

The following tests were carried out inside a bucket with the automated Cartesian system. This consists of a robotic arm connected to a computer, from which the movement speed can be programmed, (although all the tests have been carried out at 30 mm/s). The inspected area could indeed be programmed in the Y, X and Z axis, although only one sweep has been used in X, Y, adjusting the Z axis for the distance between the object and the camera, which has always been constant for each of the inspections. The high-speed camera was attached to the system, avoiding shaking movements and thus achieving a constant speed. The documented object was the carbon fibre plate, located in a horizontal position, which was scanned at an approximate distance of 120 cm and then two consecutive tests were carried out, extracting 1100 frames from each video. By using this automated system, we observed a significant improvement in the frames position extracted from the video. Although less than half ended up being aligned, they all stood in the same plane. The obtained photogrammetric model showed which areas were better documented; the inner parts of the fibre plate weren't very well depicted, whereas the bucket's floor was correctly represented. Therefore, we proceed to carry out several tests without any object, recording only the interior surface. All the frames were aligned within the software, a step forward towards finding the proper method. The number of frames was reduced, thus speeding up the processing: between 200 and 400 frames were sufficient to generate a decent 3D model in which the frames positions were on the same plane, which matched the video documentation. The Metashape software allows exporting the location of each frame in a txt format. All that data was later processed in Matlab, through a process which allows to depict the position and inclination of the camera for each of the frames aligned. Once imported, the accuracy of the positioning can be quantitatively assessed.

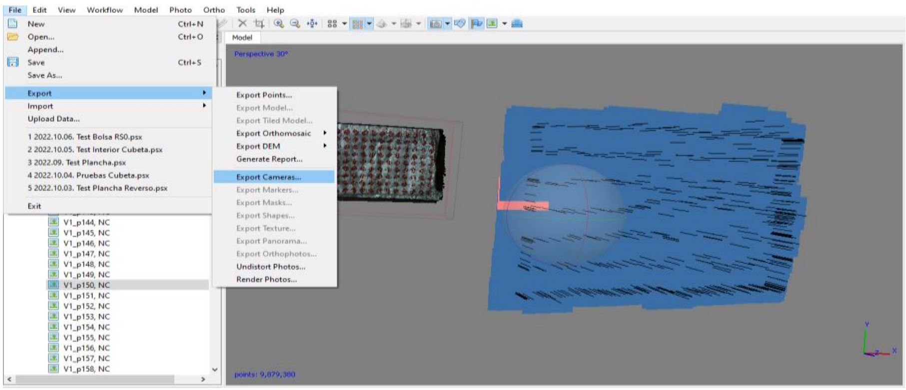

Figure 2. Metashape screenshot presenting the frame data export path.

In order to improve the method, a 100W, 5000K LED light bulb was installed on one side of the test bucket, since the variation in natural lighting can interfere with the photogrammetric results. For the following test, a remote-controlled car (55 x 25 x 17 cm) was documented. The alignment of three different point clouds was carried out, using 390 frames each and incorporating the homogeneous LED lighting. While the frames' position tended to be more homogeneous, so we started to build a pattern.

2.2.3 Single lens reflex camera method

The last part of the tests has been carried out using a SLR NIKON model D5300, to make a comparison between the frames obtained with the high-speed camera and the pictures. The camera is positioned horizontally, parallel to the bottom of the tank and on the automatic scanning arm; the manual mode was selected and the parameters were adjusted so that the pictures were balanced in lighting. The first object to document was the remote-controlled car, performing two consecutive sweeps to compare the correct location of the camera between them after aligning the photographs, obtaining the dispersed point cloud. In the first instance, an automatic camera shot is arranged every two seconds.

Test data: frames: 106, Capture mode: SLR camera. Camera to object distance: 90 cm. Automatic scanning: Y Axis: 600 x 100 cm / X Axis: 300 x 300 cm. **Shot properties**: *f* 5. Exposure time: 1/13s. Sensor sensitivity: ISO-100. Focal length: 38mm. Picture dimensions: 6000 x 4000 pixels.

The result shows that, with only a quarter of the images, better results were obtained compared to the 390 of the high-speed camera, since the number of points in the cloud are 78,974, compared to only 8,464. from the previous test. This is due to the image resolution; in the case of the SLR camera, the pictures imported were 4000 x 6000 pixels, while the video frames were only 800 x 600 pixels. Subsequently, successive tests were carried out with the reflex camera, applying the same method to other elements, varying different parameters, specifically the distance from the camera to the object, in order to simulate the conditions of the inspection at Tecnitest.

Figure 3 shows the robot arm positions in a rectangular sweep from the exported data using Metashape. Processing these data in the central areas, where it can be considered that the speed of the robot is constant, it is obtained that the average distance between two consecutive photos is 1.83 cm and the standard deviation is 0.11 cm. This represents a relative positioning error of approximately 6%. This error groups both the inaccuracies due to the method of positioning the cameras as well as those of the movement of the robotic arm itself and the vibrations of the camera support. The precision in the inclination of the camera can be obtained in an analogous way. In the Cartesian sweep, the inclination angles have not changed, so they can be considered constant throughout the inspection. Taking this into account, the calculated mean angles and their deviations expressed in degrees have been: THETA= -0.0+-0.1, PHI=-1.0+-2.7 and ROT=175.7+-2.5.

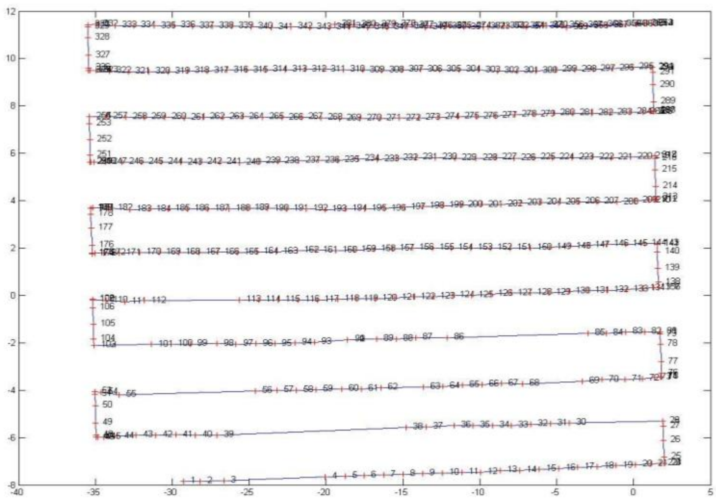

Figure 3. Matlab results of the robotic arm movement based on the location of each frame from the point cloud exported from Metashape (distance units in cm).

3. Results

The methodology studied in Section 2 was applied at Tecnitest facilities using an industrial robot. It was concluded that this methodology is able to detect the exact location of the robotic arm using photogrammetric techniques. For that purpose, a series of experiments were performed; the results obtained can be seen in Figure 4.

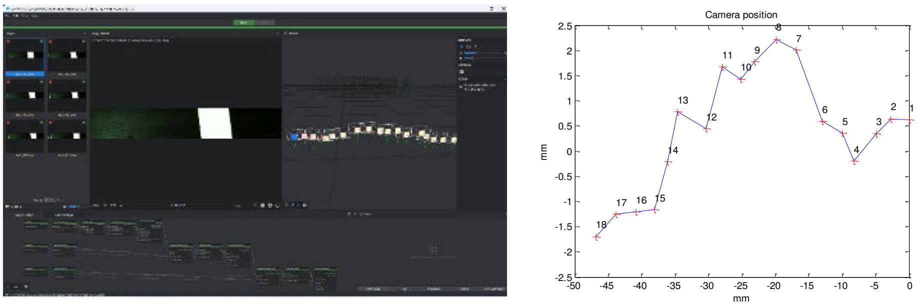

Figure 4. Matlab results of the robotic arm movement based on the location of each frame from the point cloud exported from Meshroom at Tecnitest facilities.

4. Conclusions

After seeing the results of the methodology previously presented, it has been demonstrated that it is possible to apply photogrammetric techniques in order to precisely indicate the exact location of the robotic arm. A relation is obtained to each of the video frames or pictures taken during its sweep or trajectory, as well as the inclination. The main drawback of this method is that it requires adapting the robotic system to be able to install the camera and lighting system that are needed for the calibration sweep. But it is a viable alternative if there are circumstances in which self-calibration with an ultrasound system itself does not produce satisfactory results. To sum up, this new methodology can be easily applied to the commercial industrial robots when performing non-destructive testing inspections in order to ensure the synchronism between the movement of the robot and the acquisition of the data.

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References and footnotes

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