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INTRODUCING ADAPTIVE VISION-GUIDED ROBOTIC NON-DESTRUCTIVE INSPECTION

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ABSTRACT

Ultrasonic based Non-destructive Testing (NDT) has seen wide applications in recent years. Achieving flexible automation for such testing method is a growing research area. In this regard, enabling automated vision-guided robotic ultrasonic toolpath based NDT inspection is desirable in the manufacturing and re-manufacturing industry. The complexity of this task is augmented by the varying nature of the parts in such industries. This paper introduces an approach developed for structure from motion (SfM) based vision-guided robotic NDT inspection. An automated vision system is developed and integrated into a robotic work-cell that can produce 3D models of challenging objects with sub-millimeter accuracy. These 3D models are then used to generate the toolpath for ultrasonic probe to carry out NDT inspection. We also discuss approaches to perform image acquisition allowing to capture the object view sphere and effects of these approaches on the results of SfM. We show from experimental results that the developed automated vision system can produce high accuracy 3D models of low texture, self-similar and glossy objects, without having to perform training of input data.

Keywords: robotic inspection, vision-guided tool path.

1. INTRODUCTION

Robotic inspection of components in the Manufacturing and Remanufacturing Industry is gaining popularity at ever increasing rate. Ultrasonic based techniques have been used in robotic systems, to speed up the NDT inspection of critical components [1, 2]. Although such robotic systems have increased the inspection rates, they are based on robots which manipulate ultrasonic sensors through predefined toolpaths. The robot tool-paths are typically defined on the CAD models of the parts to be inspected. Unfortunately, new manufactured parts and components undergoing remanufacturing often differ from their respective virtual models. Therefore, robotic inspection systems are still lacking strategies to achieve flexible automation at a reasonable cost. To this end, there is an increasing need for automating robotic tool-path generation, in order to perform effective NDT inspection of components with complex geometries. Photogrammetry provides a cost effective solution to facilitate NDT inspection. 3D models produced from techniques such as structure from motion can be capable of providing the tool-path for UT scan with sub-millimeter accuracy. In this paper, we present vision guided robotic component inspection for manufacturing and re-manufacturing industry. We have developed a robotic vision system that captures images of an object in the robotic work-cell, process the collected images using SfM and produces 3D model of the object with sub-millimeter accuracy. This 3D model is used to provide the tool-path for a robot to perform the NDT inspection using an ultrasonic probe. Visual 3D reconstruction is the process of generating a computer model of the 3D appearance of an object from a set of 2D images and provides an alternative to costly and cumbersome 3D scanners. Typical machine vision cameras are cheap and lightweight and can provide any object's 3D profile. In the projection process, the estimation of the true 3D geometry is an ill-posed problem (e.g. different 3D surfaces may produce the same set of images). The 3D information can be recovered by solving a pixel-wise correspondence, using multiple images. Automating the 3D reconstruction of components in the manufacturing and re-manufacturing industries is challenging due to the variability of the size and geometry of the components to inspect. Despite of the rise and success of deep learning techniques [3, 4], the 3D modelling of such variable objects remain difficult. Since deep learning techniques rely on extensive training phase and due to the varying nature of components for manufacturing and re-manufacturing industry, we propose using traditional SfM technique [5] to develop an autonomous 3D vision system. Our work aims at producing complete and accurate 3D models. Since SfM-based 3D reconstruction techniques are sensitive to environmental factors such as motion blur, non-uniform lighting, and changes in contrast, the image acquisition method influences the resulting 3D model. To achieve sub-millimeter accuracy for 3D models produced by SfM, an automated image acquisition system is developed and integrated into the robotic framework. The contribution of this work to the existing state-of-the-art is two-fold:

1) The work compares different image collection techniques and presents results of each method on SfM produced 3D models.

2) The work introduces the use of accurate 3D models, produced by the 3D vision system, to produce vision-guided robot tool-paths for ultrasonic NDT inspection.

A review of the related background knowledge and the full description of the developed system will be given in the full paper following this extended abstract. The following presents a high-level overview of the proposed system and some preliminary results that give an idea of the obtainable performance.

2. OVERVIEW

Our vision guided robotic component ultrasonic inspection system consist of KUKA KR6 R900 robotic arm [6], a standard machine vision RGB camera and ultrasonic wheel probe mounted at the end effector of the robot.

Since many components used in the manufacturing industry are self-similar, have low texture and are reflective in nature, the input images given to SfM play a critical role in producing complete and accurate 3D models. The completeness and accuracy of 3D models generated facilitates the ultrasonic based component inspection thoroughly. For this purpose, we have developed an automated image acquisition system as part of our 3D vision system, that is able to perform image acquisition for a given sample object in the robotic work-cell. Furthermore, this image acquisition system is equipped with four different approaches to scan the object in the work-cell in order to capture images containing rich and diagnostic visual cues; vital for producing complete and accurate 3D models based on SfM.

Images collected from the image acquisition system are used to produce sparse point cloud of the sample object using standard SfM and dense point cloud is obtained by using PMVS2 [7]. The dense point cloud is further processed to obtain a mesh and finally integrated into the in house developed KUKA KR6 R900 robot control graphical user interface (GUI). The GUI (see Fig. 1), represents the reconstructed mesh in the in the virtual simulation environment of the robotic work-cell.

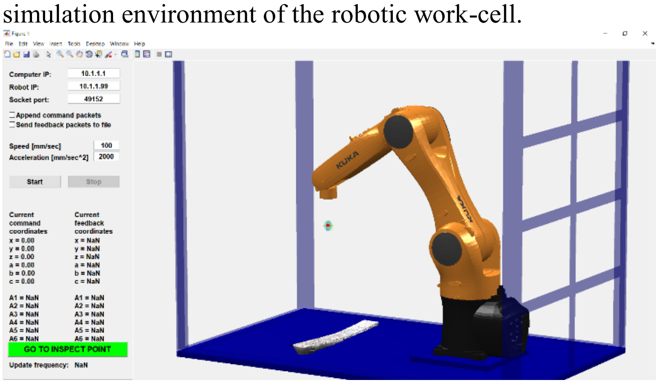

FIGURE 1: GRAPHICAL USER INTERFACE TO IMPORT THE RECONSTRUCTED PART GEOMETRY AND EXECUTE VISION-DRIVEN NDT INSPECTION.

This allows for pre planning the robot action by selecting a surface point on the mesh, providing easier access for the operator. Robot actions is then invoked by finding the pose/tool-path for an ultrasonic wheel probe to approach the selected point along the normal and carry out the NDT inspection for a selected point on the component mesh.

3. RESULTS

This section presents the results obtained from the experiments to evaluate and validate our vision guided robotic component inspection for manufacturing and re-manufacturing industry. Firstly, we validate the capability of our 3D vision system achieving sub-millimeter accuracy for the 3D models by comparing the obtained mesh surfaces with their respective CAD models. Secondly, we demonstrate the accuracy and repeatability of our vision guided robotic component inspection system.

3.1 Aluminum stair sample

Figure 2 shows the 3D reconstructed mesh produced for the aluminum sample resulting from images obtained through raster toolpath. The artefacts on the sides of the mesh are trivial since, with raster scan, the sides of the aluminum sample object were unable to be imaged entirely. The surface analysis of the obtained mesh on the CAD model is shown in Figure 3. A distance standard deviation of 2.77 mm is achieved.

FIGURE 2: MESH OF ALUMINUM STAIR.

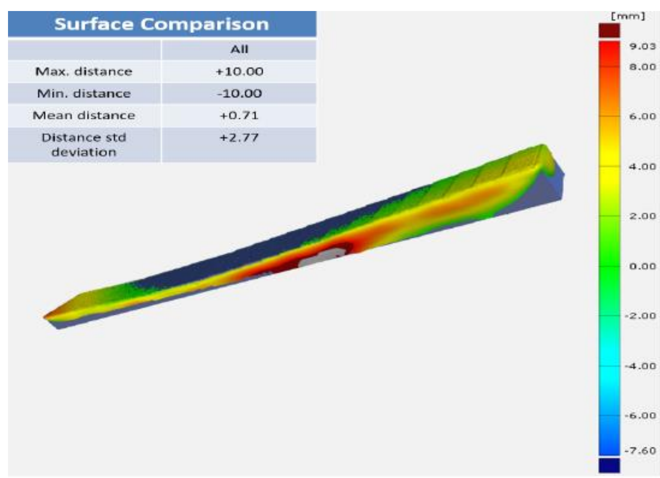

FIGURE 3: SURFACE ANALYSIS OF THE ALUMINUM STAIRS MESH ON ACTUAL CAD.

3.2 Pipe segment

Three different robotic paths were used to acquire SfM pictures and reconstruct the geometry of a pipe segment. The three tool paths were: polar raster scan, hemispherical spiral and paraboloid spiral. The three resultant meshes are illustrated in Figure 4. Both the polar and the hemispherical spiral-type tool path produced image datasets with center of the focus at the top of the object, resulting in incomplete and deformed mesh at the bottom of the pipe segment. Moreover, the polar tool-path produces redundant images due to revisiting the same camera position multiple times. The best reconstruction results are related to the paraboloid spiral-type tool path. A summary of quantitative results, reporting the mean and the standard deviation of the deviation relative to the CAD model of the samples, is given Table I.

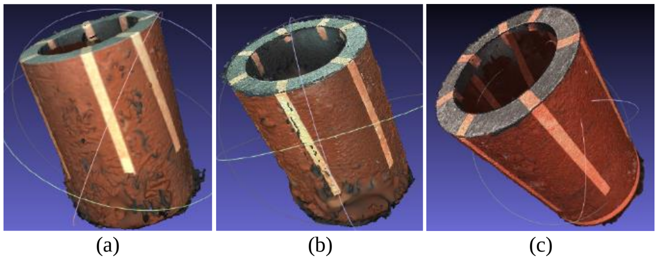

FIGURE 4: RESULTANT MESHES OF THE PIPE SEGMENT FOR THE THREE IMAGE ACQUISITION APPROACHES: POLAR RASTER (A), HEMISPHERICAL SPIRAL (B) AND PARABOLOID SPIRAL (C).

TABLE I: SUMMARY OF THE RESULTS OBTAINED FROM ALL TOOLPATHS

Component Type	Toolpath Type	No. images	Mean (mm)	STD (mm)
Aluminium step-stairs	Raster	600	0.71	2.77
Pipe segment	Polar	2298	-0.68	2.53
	Hemispherical spiral	2294	-0.30	2.34
	Paraboloid spiral	857	-0.65	1.28
	Paraboloid spiral (sub-area)	857	-1.28	0.43

3.3 Vision guided robotic component inspection

To demonstrate the validity of our proposed robotic component NDT inspection system, the toolpath generated by the 3D vision system is used to perform the robotic component inspection for ultrasonic measurements. For this purpose, we have evaluated our proposed system on the top surface of the aluminum step-stair sample.

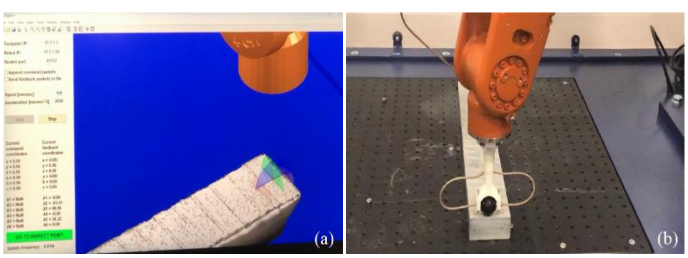

FIGURE 5: VISION GUIDED ROBOTIC COMPONENT NDT INSPECTION: AN OPERATOR SELECTING A POINT ON THE SURFACE OF THE 3D MODEL INSIDE THE GUI (A) AND ULTRASONIC WHEEL PROBE APPROACHES ALONG THE NORMAL OF THE POINT FOR DATA MEASUREMENT (B).

4. CONCLUSION

We have presented an automated vision-guided robotic ultrasonic toolpath based NDT inspection system. The 3D vision system developed has an automated image-acquisition module that was tested with four different robot tool-paths, to produce comparative results. The paraboloid spiral tool-path has proven to be the most effective to acquire the image dataset for 3D reconstruction. Our proposed robotic vision system can produce complete 3D models, using SfM in conjunction with PMVS2, for challenging components used in a manufacturing industry. It has been proved sub-millimeter accuracy can be achieved. A software graphical user interface has been developed to demonstrate real-time control of a robot arm, specifying points of interest through the obtained 3D model. This allows a user to generate a suitable robot tool-path for guiding the probe to the area of interest and performing NDT inspection, using an ultrasonic wheel probe attached to the end effector of the robot. Current work is focusing on investigating methods to automatically detect suspicious points on the surface of an object, using the reconstructed 3D model, in order to furtherly facilitate and speed up the robotic NDT inspection.

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