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Optical tactile probe for the inspection of mechanical components

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Abstract

Mechanical components are often subjected to tolerances and geometrical specification. This paper describes an automatic 3D measurement system based on the integration of a stereo structured light scanner and a tactile probe. The tactile probe is optically tracked by the optical scanner by means of 3D measurements of a prismatic flag, rigidly connected to the probe and equipped with multiple chessboard patterns. Both the stereo vision system and the tactile probe can be easily configured enabling complete reconstructions of components having complex shapes. For instance, structured light scanning can be used to acquire external and visible geometries while tactile probing can be limited to the acquisition of internal and hidden surfaces.

Keywords: Optical touch probe; Geometrical inspection; Reverse Engineering

1. Introduction

Reverse Engineering (RE) techniques [1] are widely used in all branches of modern manufacturing industry. In the field of mechanical engineering and industrial manufacturing, RE refers to the creation of geometrical documentation data from existing physical parts [2]. With the rapid development of Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) technologies, RE technology has become a significant tool to shorten the product development cycle. When original drawings are not available, it is

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often required to reconstruct CAD models from the existing parts by exploiting digitization techniques. These models can be used to optimize the design process through numerical analyses in order to improve the product effectiveness. Moreover, 3D printing, one the most representative technologies for Industry 4.0, can be adopted to generate components directly from CAD data in a very short time, thus defining more efficient, value-added manufacturing processes.

In general, the shape of an existing physical model can be retrieved by using contact or non-contact measuring devices. Traditional point-by-point systems, as mechanical probes, or full-field optical scanners may be adopted to acquire target surfaces even characterized by complex geometries. Coordinate Measuring Machines (CMMs) with contact probes provide measurements with high accuracies [3]. However, on-site measurements are not allowed due to the bulky equipment, which is usually restricted in dedicated measurement rooms. Articulated arms, characterized by 6 or 7 DoF, can be alternatively used [4]. These systems, equipped with either a laser line scanner or a touch probe, can be manually moved with respect to the target object and may result particularly effective for on-site measurements. The main drawback of CMMs and articulated arms is that they only provide a limited number of sampling points and are not suitable if free-from shapes must be reconstructed. Among non-contact approaches, optical methods based on the triangulation principle are able to provide full-field measurements with minimal interaction with the operator. Laser line scanning and structured light scanning can be indifferently used to obtain dense point cloud data on the measured surfaces [5]. Marker-based systems are also used in practical applications [6] but suffer the same limitation in the number of acquired points.

All the above-described approaches, however, have inherent limitations in the reconstruction of complex surfaces. Optical techniques allow the acquisition of visible surfaces, whereas the digitization of internal geometries (i.e., slot, holes) is subjected to partial or complete restrictions due to optical occlusions. Tactile probing methods are hampered by the cumbersomeness of the equipment (CMMs), which lowers flexibility and portability, and/or kinematic of the linkage structure (articulated arms) which limits the ergonomics of the process thus preventing the acquisition of complex hidden geometries. For this reason, complete reconstructions providing visible and internal geometries should be obtained by integrating contact and non-contact methodologies.

In this paper, an automatic and versatile 3D measurement system has been developed by integrating tactile and optical probing. In particular, a hand-held tactile probe and a stereo structured light scanner are combined with the aim at performing reliable multi-sensor measurements of mechanical components. The tactile probe is optically tracked by the stereo camera system of the optical scanner by means of 3D measurements of a prismatic flag, rigidly connected to the probe, and equipped with multiple chessboard patterns differentiated by a QR code. The probe configuration has been designed to provide both versatility and adaptability to various applicative contexts. The adoption of multiple planar surfaces reduces the stereo occlusion problem thus increasing the number of tracked points always visible by the stereo vision system in spite of the hand orientation. Moreover, a suitable calibration process has been developed by exploiting the structured light scanner in order to relate the probe tip with respect to the tracking flag. A wireless control of the stereo cameras has been implemented with the aim at enhancing the ergonomics of the tactile probing process since the operator may accomplish the measurements without removing the hand from the probe handle. Although some commercial solutions of optically tracked touch probes have been proposed [7-9], their effectiveness in the reconstruction of actual industrial parts has not yet been fully evidenced. Moreover, the designed multi-sensor system allows the integration of full-field optical measurements of visible surfaces with point-by-point contact measurements performed by the hand-held tactile probe. The geometry of the probe stylus is designed in order to allow the probing of non-visible internal surfaces, making possible complete reconstructions of components having complex shape. The whole system has been developed with the aim at carrying out on-site measurements even in non-collaborative environments, thus bypassing typical limitations of CMMs and articulated arms. The effectiveness of the proposed solution has been finally tested in the acquisition of mechanical components.

2. Proposed approach

The proposed approach is based on the integration of a stereo structured light scanner with a hand-held touch probe (Fig. 1). The overall measurement tool is based on the stereo triangulation principle. When a scene is acquired by two independent and calibrated cameras, it is possible to determine the 3D coordinates of each point in the scene