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Path planning of a laser-scanner with the control of overlap for 3d part inspection

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Abstract

This paper proposes a new approach to scan path planning for automated inspection of manufactured parts with an industrial robot based on the control of the overlap between 2 successive scanning paths. The novelty lies in the use of the least-squares conformal map, which stretches a 3D surface on a 2D plane. Equidistant paths calculated in the 2D space are transformed into equidistant paths in the 3D space. Controlling the overlap can maximize the coverage region on the scanned part. On the other hand, digitizing quality is ensured by managing the sensor configuration relatively to the part with respect to quality criteria. The approach is implemented with success for a laser-plane scanner mounted on an industrial robot.

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1. Introduction

In the context of 3D surface inspection using a laser-scanner, scan path planning is still a major challenge to obtain a complete representation of the surface in a minimum amount of time with a given scanning quality. Scan path is defined as a set of relative scanner/part configurations or driven points ensuring the quality of the acquired data according to various constraints such as visibility of the surfaces, completeness, admissible density or noise. In addition, scan path planning is even more related to other constraints like optimization of overlap and scanning time, etc. Finding the optimal strategy to scan a part, defined by its CAD model, is an issue widely addressed in the literature. Most authors base their approach on visibility and quality constraints.

Determining driven points based on the concept of visibility consists in finding the surface portions which are seen through a scanner configuration that means the surface portions that belong to the field of view (FOV) of the scanner. The field of view is the part of the laser beam which is visible by the scanner camera. Considering the laser-scanner mounted on a CMM, Bernard and Véron propose an automatic inspection process for a complex 3D part based on three levels of visibility: local visibility, global visibility and real visibility [1]. From the CAD model, Xi and Shu determine the optimal parameters of the scanner FOV to maximize the portion of scanned surface [2]. The surface is divided into sections by cutting the CAD model using parallel cross-sections. For each section, the optimal position is obtained by aligning the top of the FOV with the upper boundary of the surface profile. Derigent *et al.* propose to use the notion of global and local visibility through 2D visibility maps [3]. In addition to visibility, some studies propose to define driven points according to quality criteria. Prieto *et al.* [4] propose to keep the scanner normal to the surface, while following a quality criterion depending on the scanning distance and the view angle of the scanner. Mahmud *et al. [5]* build the scan path by limiting the number of orientations of the laser-scanner, and considering an optimal

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digitizing distance defined as the middle of the scanner FOV. The approach developed by Lartigue *et al.* [6] relies on the representation of the part surface as a voxel map, for which the size of each voxel is defined according to the size of the scanner FOV. A unique point of view is associated to each voxel according to visibility and quality criteria. The latter are defined by admissible ranges of digitizing distances and view angles.

Wu *et al.* [7] propose a path planning method for surface inspection for a structured light scanner mounted on robot having 6 degrees of freedom. In this case, the scanner trajectory is defined as a set of discrete points of view, which must satisfy several constraints: field of view, scanning distance, scanning angle and overlap. First, a wireframe representation of the CAD model is extracted as the projection contour of the model in the main direction, which is computed by the mean of all the normal vectors in the model. Next, the model is divided into several digitizing regions using the rectangle which its dimensions are defined by the FOV of the scanner and the overlap constraint. Koutecky *et al.* [8] have recently described a method for planning scan paths of a ATOS system mounted on a KUKA robot. The surface in the form of a polygonal mesh is divided into cubes, according to the FOV and to the scanner depth of view. The driven point calculation is then carried out using the Combined Visibility Map concept. The objective is to compute the orientations of the system in order to have the greatest number of visible polygonal facets as possible. Larsson and Kjellander propose an approach for scan path planning using a laser-scanner mounted on a robot for unknown objects [9]. A first scan is made from four orthogonal directions; the scanner is positioned at the limits of the working space of the robot. From data acquired during this first scan, a shape scan step is performed to retrieve the approximate shape of the object.

Most of the methods previously detailed consider the scan path as a discrete set of points of view, which are defined according to quality and visibility constraints. Only a few studies address the issue of a continuous and smooth scan path built from the discrete points of view. Scanning overlap between 2 successive paths may alter scanning time and quality (Fig.1). Overlapping zones generally present a higher scanning noise.

Overlapping control has been more studied in relation to tool-path planning for machining or gun-path planning applied to painting using an industrial robot. In this case, the control of the overlap is essential to obtain the desired paint thickness and uniformity. Paint path planning thus presents similarities to scan path planning. In order to minimize time cycles as well as to control paint thickness uniformity, painting path strategies controlling painting overlap have been proposed in some studies [10, 11]. In their approach, Andulkar et al. [10] calculated the optimal overlap distance between two consecutive passes according to the distribution model of the paint. In [11], the authors show that the generation of a spray gun trajectory that uniformly covers the surface not only relies on the definition of the path orientations and the spacing between passes but also on the
speed along the passes, which is not necessary in scanning.

Controlling the overlap between two successive scanning passes also presents similarities with constant scallop-height tool path methods for milling. Most methods proposed in the literature are developed for continuous surfaces [12, 13]. Some

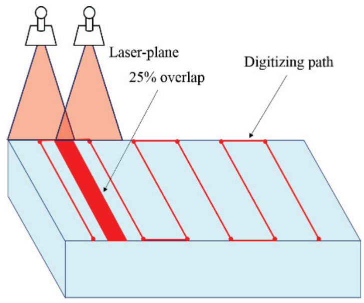

Fig.1. Definition of the overlap.

recent works propose an interesting approach more dedicated to tessellated surfaces, based on the conformal map [14, 15]. The 3D mesh surface is stretched onto a 2D plane using the conformal map. The advantage of the conformal map is to locally preserve the shape. The distances and the areas are only changed by a scaling factor [16]. Then, equidistant paths calculated in the 2D parametric space can be transformed into iso-scallop paths in 3D space by the inverse conformal map. The great advantage here is the simplification of calculation to control the overlapping, as the tool path generation is performed in the 2D space.

In this paper, we propose a method to generate a continuous scan path planning of a laser-plane scanner mounted on an industrial robot. The originality of our approach is the use of the conformal map to control the overlap between two adjacent scanning paths. Therefore, a continuous scanning path with the control of digitizing overlapping allows the management of both the orientation and the coverage rate of the laser beam. Our paper is organized as follows: our method is detailed in section 2 followed by an application in section 3. The paper ends with some concluding remarks in section 4.

2. Control of the digitizing overlap: ISOvScan (Iso-Overlap Scan) path method

In our approach, the digitizing system consists of a laser-plane sensor mounted on an industrial robot. The part to be digitized is represented by its tessellated CAD model. The sensor trajectory is defined as a set of ordered scanner configurations, i.e. a set of positions and orientations $(C_E; \vec{V}_L; \vec{V}_C)$. The position of the scanner is defined by the point C_E , which positions the scanning laser line in the field of view: $\overrightarrow{C_0 C_E} = d^*.\overrightarrow{V_C}$. The scanner orientation is given by the couple of vectors $(\vec{V}_L; \vec{V}_C)$: the director vector of the light-beam axis $\vec{V}_C$ and the director vector of the digitizing line $\vec{V}_L$ (Fig. 2).

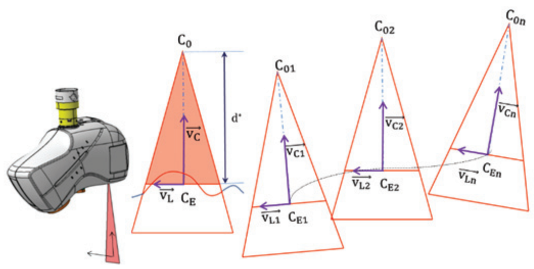

Fig.2. Parameters defining the scanner path [17].