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ScienceDirect

Robotics and Autonomous Systems 56 (2008) 615–624

Robotics and Autonomous Systems

www.elsevier.com/locate/robot

Path planning for laser scanning with an industrial robot

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Received 30 May 2006; received in revised form 2 October 2007; accepted 11 October 2007
Available online 25 October 2007

Abstract

Reverse Engineering is concerned with the problem of creating CAD models of real objects by measuring point data from their surfaces. Current solutions either require manual interaction or expect the nature of the objects to be known. We believe that in order to create a fully automatic system for RE of unknown objects the software that creates the CAD-model should be able to control the operation of the measuring system. This paper is based on a real implementation of a measuring system controlled by CAD software, capable of measuring along curved paths. Some details of the system have been described in earlier publications. This paper is concerned with the problem of automatic path planning for a system that can move along curved paths.

Keywords: Reverse engineering; 3D measurement systems; Laser scanner; Path planning; Cross-sections; Industrial robot

1. Introduction

In the development of new products CAD systems are often used to model the geometry of the objects to be manufactured. Reverse Engineering (RE) of geometry is the reverse process where the objects already exist and CAD models are created by interpreting geometrical data measured directly from the surfaces of the objects.

An introduction to RE which is often referred to is a paper by Varady, Martin and Cox 1997 [1]. In that paper the RE process is divided into the following four steps:

(1) Data capture
(2) Preprocessing
(3) Segmentation and surface fitting
(4) CAD-model creation.

Step 1 is closely related to measurement technology. Optical systems such as laser scanners in combination with manually-controlled mechanisms for orientation are often used to measure the 3D coordinates of large numbers of points from the surface of the object. In the context of automatic RE, however, we are only interested in systems where the scanner orientation is controlled by the RE software itself.

A simple system of that kind is achieved by combining a fixed scanner with a turntable. See [2] for a description of such a system. A more flexible solution is described in [3] where a coordinate measuring machine is used in combination with a laser scanner. A recent development by the same author is presented in [4]. Another autonomous system is described in [5], where the authors use a range camera, a turntable and an industrial robot. This setup may appear similar to what we will present here, but their robot does not move during scanning, so their path planning is only a NBV (Next Best View) problem.

We have developed a measuring system based on a laser profile scanner mounted on the arm of an industrial robot. Both are connected with our system through TCP/IP. This makes it possible to scan an object from any direction even along curved paths. The hardware and basic system configuration is described in [6]. We have also developed the software needed for robot motion and data capturing, see [7]. A key ability in our system is the possibility to scan along curved paths. For some situations this may not be needed to get a good result, there will, however, always exist situations where this gives better results in terms of fever scans needed and/or avoiding occlusions. For an automatic system a path planning approach that support scanning along curved paths is therefore desirable. This issue is addressed in this paper.

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0921-8890/$ - see front matter
doi:10.1016/j.robot.2007.10.006

In order to reach all surfaces of the object many individual scans may be needed. Each scan then produces a pointcloud that needs to be merged with pointclouds from earlier scans. The problem of determining the number of scans needed and how to orient the measuring system relative to the object in each individual scan is usually referred to as path- or view-planning. A survey of planning techniques for automated data capturing and preprocessing is given in [8].

The sequential RE process as described by Varady, Martin and Cox in [1] was not meant to be fully automatic. We believe that an automatic procedure should be iterative. In [6] we proposed an automatic procedure for RE of unknown objects based on three steps. The first step *Size scan* is concerned with the problem of determining the overall size of the object. The next step *Shape scan* should perform an automatic scanning, covering the objects surface. The result from the shape scan represented by, for example, a pointcloud or a triangle mesh are directly useable for some purposes and can be regarded as a measurement result. We also proposed the possibility to add a third step *RE scan*, in which the system can use the intermediate facet/point model to plan more accurate scans required to create the final CAD model.

This paper is concerned with the first two steps. Algorithms and implementations of *Size scan* and *Shape scan* are presented with test results. Our work will now continue with the last step of the process and we hope to present a working implementation of this in papers to come.

2. Size scan

The maximum working volume of our system is defined by a vertical cylinder 650 mm high and 250 mm in radius. These values are determined from the reachability limits of our hardware setup. The purpose of *size scan* is to reduce this volume to the size of the object in terms of its bounding box. The object coordinate system is located with its origin in the centre of the turntable and the bounding box is simply the max and min coordinates of the object along the three axes of the coordinate system.

Size scan is made by scanning with vertical strokes from four orthogonal directions. Due to the limited size of the scan window, scanning is performed by stepwise approaching the centre of the coordinate system until materia is found. When all four directions are processed, the distance from the centre in each direction together with the highest detected point defines the bounding box of the object. The lowest point is by default set to a value slightly above the turntable. If a fixture is used to raise the object above the turntable, the height of the fixture is used instead; see, for example, Fig. 9(a).

Since accuracy is not a critical issue, *Size scan* can be performed with relatively high speed. We have used 30 mm/s which with our equipment will yield capture of profiles at 10 mm spacing.

3. Shape scan

The *Shape scan* module is more complex. It starts with the assumption that the objects bounding box is known and ends with an approximate model accurate enough for planning step 3 in the RE process, segmentation and surface fitting. The algorithm is iterative and each new scan path is planned individually based on the information available at that moment. Each scan path creates a pointcloud that represents some part of the object and we are thus faced with the problem of merging local pointclouds into a global model. We also have to ensure that all parts of the object are scanned and establish the end criterion that lets us know when the process is finished.

The survey by Scoot and Rooth [8] describes several planning techniques that could be used for this purpose. We decided to develop a method influenced by the OCS model published by Milroy, Bradley and Vickers in [9]. The reason for this choice is mainly that the OCS model facilitates the merging of individual scans into a global model, it also reduces the amount of data compared to a triangulated pointcloud but still captures sufficient information about the surface of the object to support path planning.

3.1. The OCS model

The OCS model (Orthogonal Cross-Sections) is created by first triangulating each local pointcloud and then intersecting it with a number of equispaced x, y and z cutting planes, thus creating three curve sets referred to as a local section. Each local section is then merged with the global model (the sections from previous scan paths) by discarding portions that overlap, adding the new sections and making appropriate connections to form continuous curve segments. Free curve ends indicate portions of the object not yet scanned and are thus used to plan the next scanning path.

3.2. The local section

As described in [7] pointclouds generated by scanpaths are registered by the Varkon CAD-system [10] and stored as MESH objects. A local section is created by intersecting a MESH with planes parallel to the global yz-, xz- and xy-plane respectively. The same planes are used for all local sections. In [9] the authors use equispaced planes with a distance of 3 mm. In order to get a reasonable reduction of data the distance between two parallel planes, the OCS-distance, should be large compared to the size of the MESH triangles. Our equipment is designed to scan about 5–10 times larger objects than Milroy et al. [9] used in their experiment. The cross-section distance used in the test examples presented here is 5 and 10 mm.

For each plane we find all triangles that intersect. The result is a set of intersection lines, one set for each plane. Next, we connect the lines to continuous sets. This is done by connecting each line in a plane with a line in the same plane that shares one of its end points. The result is one or more ordered linesets representing continuous portions of the surface of the object.

Next step in creating the local section is to reduce the number of lines in each lineset using an algorithm that removes lines in regions with low curvature. This is done by a simple chord height calculation and two lines that don't contribute enough are discarded if they can be replaced by a new line