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Error sources in a 3-D reverse engineering process

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Abstract

The repeatability and accuracy of the digitizing process in a reverse engineering or 3-D inspection process becomes critical when destructive methods are used for data capture, as the part is no longer available for verification by other methods. This paper deals with the error sources in a destructive 3-D reverse engineering process. In this process, the part is encapsulated in epoxy and the encapsulated part is milled one layer at a time using a fly cutter with a small layer thickness. The freshly cut surface is scanned and images of different layers are merged to give 3-D point data for the part. Various sources of errors contributing to overall error in accuracy and repeatability of the process have been identified and their effects are discussed. The study showed that the threshold setting for image processing and mill-head vibrations have significant effect on accuracy and repeatability, respectively.

Keywords: Capture geometry inside; Accuracy; Repeatability; Error sources

1. Introduction

Reverse engineering or 3-D inspection, defined as the development of the technical data for an existing part for which no technical data is available [1], has become an integral part of modern manufacturing practices. The various applications [2] of reverse engineering include digitization of a new design, design of damaged parts where drawings are not available, and inspection. The digitizing process can be classified into two major types:

(a) Destructive methods
(b) Non-destructive methods

The destructive methods include slicing/scanning processes and the part is destroyed in the process. The non-destructive methods, which measure the surface geometry, can be further classified into contact and non-contact methods. The former includes touch probes and CMMs [2], while the latter includes laser-based triangulation, grating projector, moiré interferometry, CT, MRI and scanning using a camera [4]. The non-destructive methods have a limitation that they cannot capture the internal features of the part. The destructive methods are used where internal features are of importance or for a part whose features are not accessible using non-destructive methods.

The slicing/scanning process for reverse engineering or 3-D inspection is used to gather three dimensional point cloud data representing the processed part. Commonly this system consists of a milling machine and a scanning unit. The schematics of the machine and the machine co-ordinate system that are used in our study are presented in Fig. 1. The part is encapsulated in epoxy and the encapsulated part is milled one layer at a time using a fly cutter with a small layer thickness (in the order of 25 μm). The surface is scanned and images of different layers are merged to give 3-D point data. This point cloud data is then processed to give information about the part dimensions. The color of epoxy for encapsulation is chosen so as to have contrast with the part for a better image. For example, in case of Delrin parts white epoxy is used, while for an Aluminum part a black epoxy is used. The part is positioned preferably at an angle of 45° relative to the cutting plane for best results. Immediately after encapsulating the part in epoxy, it is treated in a pressure vessel having alternate pressurized and vacuum states for 8 h. This is done to remove any air bubbles in the epoxy and for proper filling of epoxy in the crevices of the part. The machine is calibrated with reference to an optical grid shown in Fig. 2 before every test to get accurate image size.

A system with high accuracy and repeatability has a lot of applications not only in obtaining the point cloud data for parts where previous data is not available but also in the inspection process of produced parts. The data collected from the inspected part can be compared with the standard CAD

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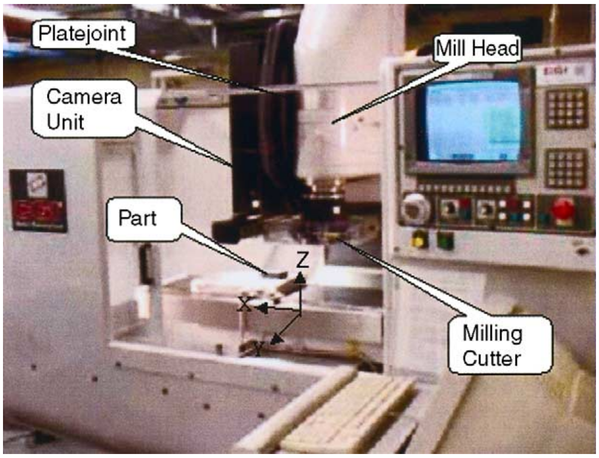

Fig. 1. Machine set up and machine co-ordinates.

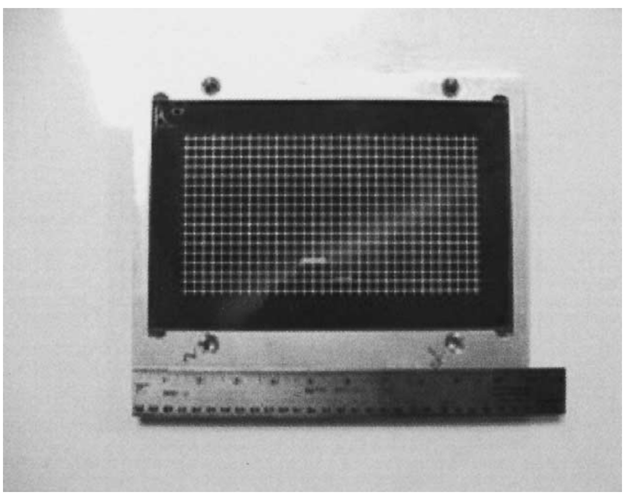

Fig. 2. Optical grid.

model to reveal any differences between the CAD model and the actual part. The accuracy and repeatability of the machine becomes critical in case of intricate objects with internal features, as the very purpose of the process is to measure intricate details of the object, which are not possible to measure by conventional measuring systems. A comparison of different measuring systems is presented in Table 1.

Table 1
Comparison of different measurement methods

Measurement method	General accuracy level (mm)	Limitation
Calipers	±0.004	Can only be used for simple dimensions
Micrometer	±0.0025	Can only be used for simple dimensions
CMM	±0.0025	Time consuming process, difficult to measure internal dimensions
Laser scanner [7]	±0.025	Cannot measure internal dimensions
CGI system [14]	±0.02	Part gets destroyed

2. Previous work

Most researchers have worked to develop new techniques for data collection or data processing. The majority of the work has been done on non-destructive methods involving lasers [7,9,13]. There is only one reference on a system similar to the one studied in this paper. The process capability of this system, defined as error plus three times the standard deviation in measurement, was established at Eastman Kodak Company [3]. The study at Eastman Kodak Company reported an error of ±38 μm and their study did not include machine tool repeatability and accuracy, and machine-related effects like thermal expansion, vibration, etc. A similar system [4] was developed at Xi'an Jiaotong University, Xian, China, which achieved higher accuracy and resolution by the use of a higher resolution camera with a resolution of 9600 dpi. The camera used is a Mirage D-16L. This system is suitable for a work size of 400 mm × 300 mm × 400 mm (16 in. × 12 in. × 16 in.). It can reach an accuracy of 5.4 μm and a resolution of 2.7 μm for obtaining the 2-D edges. However, no literature is available about the sources of error in that system. A lot of work has been reported on minimizing errors during image processing [5–10]. The error minimization is primarily done by incorporating geometric constraints based on the design intent and features of the part. Ramesh et al. [11] and Bohez [12] have discussed error compensation methods in machine tools. There is a lack of literature, however, regarding the process characterization or probable sources of error in systems similar to the Capture Geometry Inside (CGI) system [14]. In this paper, various sources of error have been identified for the CGI system CSS-1000 made by CGI, Eden Prairie, Minnesota.

3. Probable sources of error

The reverse engineering system studied in this paper can be divided in two major parts:

1. Slicing system
2. Imaging system
   (a) Camera
   (b) Software

The different causes of error identified are:

Slicing system	Imaging system
1. Interaction between tool and work piece	1. Camera lens focus
•Heating	2. Distortion in lens
•Interaction forces/ vibration	3. Camera alignment
•Effect of tool condition on image quality	4. Electromagnetic interference in camera circuit
•Epoxy support/ non-support	5. Lighting conditions