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Title :

Study on Inspection and Verification of 3D Point Cloud Datasets Registration for Reverse Engineering Application

Thesis Outline:

The objective of this work is to assure 3D model built from point cloud datasets registration conform to the reversed object. Dataset errors and registration errors are the primary sources of failure in pursuing a precise duplication part. Firstly, two new segmentation methods are proposed, i.e., ICP (*Iterative Closest Point*) registration utilized extracted plane features, and ICP registration used extracted point features. Secondly, a novel method of inspection and verification of point clouds registration using CMM (Coordinate Measuring Machine) data taken in correspondence with pre-defined object features. Thirdly, Direct NC (Numerical Control) tool path generation from the point clouds is proposed as an addition topic to provide a practical overview. The thesis consists of 7 chapters. The contents of this thesis are organized as follows. The thesis consists of 7 chapters. The contents of this thesis are organized as follows.

Chapter 1 introduces the background of reverse engineering. Advanced devices and method are applied to retrieve object surface data. The advantages and disadvantages of measurement method and devices are briefly described in this chapter. Also, review of registration of point cloud data from laser scanning devices and current problems in this field. Problem statement and objective of the thesis with the motivation are proposed in this chapter. In addition, the prospective application of the proposed method in reverse engineering application.

Chapter 2 This chapter explains the overall algorithm and the connection of one algorithm to the other algorithm briefly. The algorithms are registration of point cloud

datasets by utilization of the pairwise plane features, registration of point cloud datasets by utilization of extracted features, inspection and verification of point cloud datasets registration using CMM datasets data taken in correspondence with pre-defined object features, and application and implementation: generation of efficient NC tool path directly from point cloud datasets registration.

In this chapter, the instruments used in this research are also described, i.e., a laser scanner and a coordinate measuring machine (CMM). The specification and the procedure the operation of a laser scanner and a CMM are explained in this chapter. Moreover, the characteristic, error types, and verification procedure of CMM are also explained in this chapter.

Chapter 3, In this chapter, the registration method between laser scanning data sets by utilizing the pairwise of plane features is discussed. The registration is applied into two steps: rough and fine registration. Rough registration was carried out using a set of transformation matrix based on the pairwise vectors generated from pairwise region of datasets. Fine registration was conducted based on the following consecutive steps. Firstly, apply the grid method to the pairwise point cloud datasets. Secondly, classify data pattern of each grid, and extract and validate plane features. Thirdly, find the intersection of the pairwise grids. Fourthly, apply validation to convince only pairwise plane features involved in fine registration. Finally, apply the ICP-based fine registration using brute force and KD-tree schemes for both point-to-point and projected points of planes onto projected points of planes.

This algorithm has several advantages and disadvantages as follows:

- **Advantages:** accurate, shorter computation, lower memory, capable to handle pairwise datasets with different density, and robust to noise.
- **Disadvantages:** effective only for reverse engineering a product with plane feature dominant, and need the good result of rough registration.

Prospective application: reverse engineering product with plane feature dominants such as casting product, machining product, and injection molding product.

Chapter 4, in this chapter, the registration method by utilization of the extracted features briefly in laser-to-laser scanning data sets is presented. The method of segmentation and feature extraction is discussed. Furthermore, the advantages and disadvantages of the methods and the problems associated with the proposed method are discussed. The comparison of the effectiveness and efficiency between the method are discussed in this chapter 4 and the method is discussed in Chapter 3.

This registration consists of rough and fine registration. Rough registration process is the same as the method proposed in Chapter 3. Fine registration consists of the consecutive steps: point cloud dataset segmentation, features extraction, feature validation and verification, boundary point extraction, and selecting feature involving in the fine registration. Point cloud segmentation is applied using region growing based on the normal vector and curvature of each point. Some criteria are used to validate each extracted feature. In this case, extracted point features of pairwise datasets are used in ICP-based fine registration using brute force and kd-tree scenario. Comparison of this proposed method with the proposed method in Chapter 3 and Besl method is also carried out.

Based on the application into two real cases, this method is more robust than the method proposed in Chapter 3. However, the fitting accuracy is lower than the method proposed in Chapter 3. Based on the inspection of the result using CMM data proposed in Chapter 5, it shows that registration method proposed in Chapter 4 resulted an accurate registration result. This proposed method is appropriate to be implemented in reverse engineering of a wide variety of product such as mechanical product, molding, casting, forging product and so on.

This algorithm has several advantages and disadvantages as follows:

- **Advantages:** accurate, capable for reverse engineering of wide range products with plane features not dominant, and capable of handling different density datasets.

- **Disadvantages:** longer computation, higher memory, good result of rough registration not too needed, and over-segmentation and under segmentation.

Prospective application: capable for reverse engineering wide range product.

Chapter 5 In this chapter, the method of inspection and verification of laser scanning data sets registration is discussed using the coordinate measuring machine (CMM). This developed method is including for both for a product with datum and without datum. This chapter also discussed the problem address to the difficulty of this approach.

The input is registration result and CMM point data. This algorithm consists of the consecutive steps. Firstly, registration of point cloud datasets obtained from point clouds registration and CMM dataset. This registration can utilize the datum references for a with-datum product. Secondly, point cloud datasets segmentation and feature extraction. Validation and verification are carried out for each extracted feature. Evaluate datum references and pre-defined critical features using corresponding CMM data in each grid. Correction is applied based on the evaluation of datum references and critical features. The output is verified registration result and dimension of important features.

This algorithm has several advantages and disadvantages as follows:

- **Advantages:** can guarantee level confidence of registration result and get more accurate data
- **Disadvantages:** while point cloud data is too unstructured, validation and verification will be failed. Since CMM-point cloud datasets registration failed, validation and verification are also failed. Time-consuming in segmentation and feature extraction process.

Prospective application: capable for reverse engineering wide range product.

Chapter 6. This chapter discusses the generation of efficient NC tool path directly from point cloud data. Firstly, machining process and cutter used are defined. Secondly, selecting the type of path will be used in this system. Some parameters can be assigned to control machining processes such as the dimension of an object, its position and

orientation, surface roughness, work piece material, and machining tolerance, and so on. The other machining parameters to be considered in the process are cutting speed, spindle speed, feed per minute, maximum chip thickness, feed per tooth, and some tooth of the cutter, feed per revolution, and depth of cut, remove rate, machining time, power, pitch and so on. Those parameters will influence the efficiency machining and surface quality of machining.

Thirdly, the tool path type is defined. In this case, iso-parametric method is selected. Fourthly, parameters of the tool are defined. In this case, the flat-end mill for rough cutting and ball-end mill for the semi-finished and finished surface are used. Fifthly, tool path with tools parameters selected are generated. In this case, grid method is used to evaluate next tool moving direction. The tool path for rough cutting and semi-finishing cutting is generated. By implementation into a real case, it can be concluded that the proposed method is very useful to create point NC-tool path directly from point cloud data.

This algorithm has several advantages and disadvantages as follows:

- **Advantages:** reconstruction of surface model is not needed so that it makes shorter computation time and lower memory.
- **Disadvantages:** difficult to achieve adaptive forward steps and path intervals, and hard to control machining accuracy and obtain smooth surface finished.

Prospective application: capable for reverse engineering wide range product that appropriates to the machining process.

Finally, in this chapter, summary and conclusion of each chapter are discussed. Also, the future works are presented in **Chapter 7**.