UNIVERSITI PUTRA MALAYSIA

COMPARISON OF CONTACT AND NON-CONTACT REVERSE ENGINEERING TECHNIQUES FOR FREE-FORM SURFACES WITH COORDINATE MEASURING MACHINE AND 3D LASER

ISMANIZAM BINTI ABD. MANAF

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By

ISMANIZAM BINTI ABD. MANAF

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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To my dear dad, mum, brothers and sisters for believing in me.

To special one, Mohammad Faeiz Ismail, thanks for your love and staying by my side.

Special thanks to Ard who never gave up in giving me her supports and inspirations.

And to others who always pray for me.

Mama, memories of you are still fresh in my mind and close to my heart.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

COMPARISON OF CONTACT AND NON-CONTACT REVERSE ENGINEERING TECHNIQUES FOR FREE-FORM SURFACES WITH COORDINATE MEASURING MACHINE AND 3D LASER

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Chair: Datin Napsiah Ismail, PhD

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Application of reverse engineering (RE) technology enables creation of Computer Aided Design (CAD) models of existing product/part by capturing the surfaces data using either contact or non-contact methods. RE process consists of four main stages from part digitization, data editing, surface generation to CAD model construction. Many researches in RE applications show CAD model of an existing part was successfully reconstructed by using CMM or 3D laser scanner, but the researches need additional task in editing stage such as developed extra programme to reduce noises and errors. Additional task in editing stage can be eliminated if part digitization stage is carried out properly since surface measurement is the first priority in RE process. In this research, a free-form (FF) surface of an automotive component was generated using contact and non contact RE methods. Four scanning techniques used with two types of CMM namely Global Status Brown and Sharpe for point to point scanning and UMESS UMM550 Carl Zeiss for line scanning and two types of 3D laser scanners such as

Cyberware 3D Rapid Digitizer for automated scanning and Minolta 3D Laser Scanner for manual scanning. The digitization strategies, scanned result and CAD models generated using both methods are then analyzed and compared. Digitization parameters for contact methods are tips radius, minimum angle, step width and scanning speed while for non-contact method are rotation sense, distance, laser density, rotation view angle, scanning mode, width, pitch and scanning angles. Point to point scanning technique with large amount of scanned data volume is most time consuming as measured while conducting an experiment that is more than 10 hours need to complete scanning time from CMM measurement to data processing. In line scanning, although small data volume gathered, it takes 3 hours 25 minutes to perform complete scanned part surface. In automated scanning required 40 minutes inclusive of processing time while manual scanning takes 1 hour 30 minutes to perform a complete scanned. It means in term of time taken, laser scan technique may reduce the RE processing time compared to tactile probing. However, while comparing to editing and modeling task, also the modeling skill required, data captured from manual scanning technique is most demanding. Point to point scanning produced best quality result compared to other technique since a prototype model is successfully produced with 1% percentage error. Most unacceptable result is manual scanning because too many missing surfaces to the surface scanned result.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERBANDINGAN TEKNIK SENTUH DAN TIDAK-SENTUH BAGI KEJURUTERAAN BALIKAN UNTUK PERMUKAAN BENTUK BEBAS MENGGUNAKAN MESIN PENGUKURAN KOORDINAT DAN LASER 3D

Oleh

ISMANIZAM BINTI ABD. MANAF

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Fakulti: Kejuruteraan

Aplikasi teknologi kejuruteraan balikan (RE) membolehkan penghasilan model Rekabentuk Terbantu Berkomputer (CAD) bagi komponen sediaada dengan memperolehi data permukaan sesuatu komponen menggunakan kaedah sentuh atau tidak-sentuh. Proses RE terdiri daripada empat peringkat utama daripada pendigitan komponen, penyuntingan data, penghasilan permukaan dan pembinaan model CAD. Banyak penyelidikkan dalam aplikasi RE menunjukkan model CAD dari komponen sediaada telah berjaya dihasilkan dengan menggunakan mesin pengukuran koordinat (CMM) dan pengimbas laser 3D, tetapi masih memerlukan kerja tambahan dalam peringkat penyuntingan seperti membina program bagi mengurangkan ralat. Kerja tambahan dalam peringkat penyuntingan boleh dihapuskan atau dikurangkan jika perhatian diberikan dari peringkat pendigitan data lagi kerana pengukuran permukaan adalah paling utama dalam proses RE. Dalam kajian ini, permukaan bentuk bebas (FF) bagi komponen automotif dihasilkan menggunakan kaedah sentuh dan tidak-

sentuh. Empat teknik imbasan digunakan melalui dua jenis CMM iaitu *Global Status Brown and Sharpe* bagi imbasan titik ke titik dan *UMESS UMM550 Carl Zeiss* bagi imbasan garisan dan dua jenis pengimbas laser 3D iaitu *Cyberware 3D Rapid Digitizer* untuk imbasan berautomatik dan *Minolta 3D Laser Scanner* untuk imbasan manual. Strategi pendigitan, hasil imbasan dan model CAD yang dihasilkan melalui kedua-dua kaedah ini kemudiannya dianalisa dan dibuat perbandingan. Beberapa parameter pendigitan dalam kaedah sentuh ialah jejari tip, sudut minima, lebar langkah dan kelajuan imbasan manakala untuk kaedah tidak-sentuh adalah putaran, jarak, ketumpatan laser, putaran sudut pandangan, mod imbasan, lebar, curam dan sudut imbasan. Teknik titik ke titik menghasilkan amaun data imbasan yang besar dan paling memakan masa iaitu lebih dari 10 jam diperlukan bagi melengkapkan keseluruhan kerja imbasan sehingga pemprosesan data. Dalam teknik imbasan garisan pula, walaupun amaun data adalah kecil, ia memerlukan 3 jam 25 minit untuk mendapatkan keseluruhan permukaan komponen. Untuk imbasan berautomatik, 40 minit diperlukan termasuk masa pemprosesan dan untuk imbasan manual mengambil masa 1 jam 30 minit untuk menyempurnakan imbasan. Ini menunjukkan bahawa teknik imbasan laser dapat mengurangkan masa pemprosesan RE jika dibandingkan dengan prob sentuh. Walaubagaimanapun, jika dibandingkan dengan kerja suntingan dan permodelan serta kemahiran permodelan yang diperlukan, pemperolehan data melalui imbasan manual adalah paling rumit. Imbasan titik ke titik telah menghasilkan keputusan yang paling berkualiti dibandingkan dengan teknik yang lain apabila ia telah berjaya menghasilkan sebuah model prototaip dengan 1% peratusan ralat. Keputusan yang paling tidak boleh diterima adalah daripada imbasan manual bilamana terlalu banyak permukaan komponen yang tidak dapat diimbas.

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I certify that a Thesis Examination Committee has met on 28 July 2009 to conduct the final examination of Ismanizam Binti Abd. Manaf on her thesis entitled "Comparison of Contact and Non-Contact Reverse Engineering Techniques for Free-Form Surfaces with Coordinate Measuring Machine and 3D Laser" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the candidate be awarded the Master of Science.

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Date: 12 August 2010

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

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ISMANIZAM BINTI ABD. MANAF

Date:

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LIST OF ABBREVIATIONS

2-D	2-Dimensional
3-D	3-Dimensional
ABS	Acrylonitrile, Butadiene, and Styrene
ABSi	Methylmethacrylate Acrylonitrile Butadiene Styrene Copolymer
C/C++	C or C++ Programming Language
CAD	Computer Aided Design
CAD/CAM	Computer Aided Design and Computer Aided Manufacturing
CAE	Computer Aided Engineering
CARE	Computer Aided Reverse Engineering
CATIA	Computer Aided Three-dimensional Interactive Application
CCD	Charge-Coupled Device
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
DEA	Data Envelopment Analysis
DOE	Design of Experiment
DOF	Depth of Field
DXF	Data Exchange Format
FDM	Fused Deposition Modeling
FEA	Finite Element Analysis
FEM	Finite Element Method
FFF	Free Form Features
FOV	Field of View

FTP	File Transfer Protocol
IDEF0	Integration Definition for Function Modeling
IGES	Initial Graphics Exchange Specification
ISO	International Standard of Organization
LAN	Local Area Network
LDM	Laser Displacement Meter
LOM	Laminated Object Manufacturing
MM	Mini Model
NC	Numerical Control
NURBS	Non-Uniform Rational B-Spline
PC	Personal Computer
PC-DMIS	Dimensional Measuring Interface Standard Software
PC-ABS	Polycarbonate - Acrylonitrile, Butadiene, and Styrene
PC-ISO	Polycarbonate-ISO
PDM	Product Data Management
PET	Polygon Editing Tool
Pro-E	Pro-Engineer
PU	Polyurethane
QC	Quality Control
RE	Reverse Engineering
RGB	Red Green Blue
RP	Rapid Prototyping
SDRC I-DEAS	Structural Dynamics Research Corporation Integrated Design and Engineering Analysis Software
STL	Stereolitography
UGNX2	Unigraphics NX2

VDA	Verband der Automobilindustrie (CAD data exchange format)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Reverse Engineering (RE) refers to the process of creating engineering design data or product technical data from existing parts (Huang and Tai, 2000 and Yuan et al., 2001). It recreates or clones existing parts by acquiring the surface data of an existing part using a scanning or measurement device (Lee and Woo, 2000). The reasons why RE are necessary because for example old products for which there are no prints, or product technical data are needed for the purpose of equipment maintenance, upgrading, or ISO 9000 documentation. Another example is where molds or dies were originally out-sourced due to lack of internal manufacturing capability and where neither blue prints nor electronic data are available in-house. With increased in-house capability in Computer Numerically Controlled (CNC) machining, there is a need to duplicate the existing molds or dies for the purpose of replacement due to wear or other damages. Products designed before computer aided design/computer aided manufacturing (CAD/CAM) existed is one typical example.

In the context of general manufacturing methods, reverse engineering is an important process for instances where a product initially exists as a designer's model in a medium, such as styling foam or modeling clay. In modern practice, and for the scope of this thesis, reverse engineering free form or sculptured objects may be defined as the process of generating a computer-aided design (CAD) model from an existing part or prototype as shown in Figure 1.1, which has changed from a skilled manual process to one incorporating sophisticated computer software and measuring instruments it usually has four main stages.

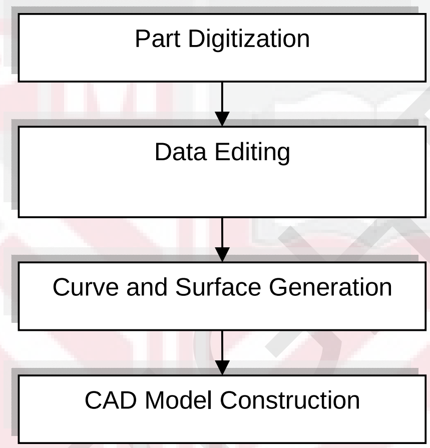

Figure 1.1: Stages in the reverse engineering process.

The process starts with 3-D data collection using these two broad methodologies to generate CAD model from digitizing or scanning data by using coordinate measuring machine (CMM) or 3D laser scanner. Methodologies of digitization parts can be classified into two general categories: contact and non-contact (Li et al., 2002, and Li and Gu, 2004). CMMs with contact probe and robot manipulators are categorized as contact method. While the 3D laser scanner is classified into non-contact method or a non-contact machine vision system, such as an optical triangulation range sensor which is used a laser light and a camera to capture the surface scanned.

A CMM consists of a workspace in which parts are fixed, a sensor for detecting the part surfaces, a mechanical assembly for moving the part sensor around the workspace, and a computer for calculating the part dimensions based on the sensor measurements. CMMs are available in numerous sizes and styles. Some are "desktop" mechanisms moved manually, while others are computer driven and are large enough to measure car bodies. CMM in reverse engineering applications become widely used with reverse engineering software that designed to take an existing physical part and construct a computer model of the part geometry based on a large number of measurements of its surface. Most contact methods are usually for more accurate measurement while non-contact methods are for faster measuring time.

An optical system, the other major type of digitizer, projects a light or laser beam onto the surface, and a camera or detector intercepts the reflected beam and converts it to coordinates. An optical system often referred to as a 3D digitizer is used for automating the reverse engineering of mechanical parts and organic shapes. Manufacturing professionals apply them to the creation of new patterns for prototype tooling, investment casting, and CNC machining. Medical specialists use 3D digitizers to digitize bones and other anatomy for the development of prosthetics and implants. Video production experts use 3D digitizers to capture hard to create shapes for TV commercials and special effects. For non-contact methods, parts are not destructive by the contacts scanning probe and generally provide much faster data collection rates.

Most RE application involved to free-form surfaces or normally known as complex surfaces. Free form features can be defined in the same way as regular–shaped features. Such features still correspond to generic shapes, the only difference being that there is more modeling freedom for the shape of the features; typically, their faces can be modeled with Non-Uniform Rational B-Spline (NURBS). Although freeform surfaces can have very complex shapes, their shape can also be simple or even regular (Van den Berg et al., 2002). Modelling freeform objects was done by directly modifying its surfaces, e.g. by selecting a point on the surface of the model and dragging it to another position, thereby deforming the object. Modelling of CAD model from scanned data can be made using any CAD/CAM packages that available in the market such as Unigraphics, CATIA, Pro-Engineer and Solidworks software. The model creates depends, of course, heavily on the representation that is used for the freeform object.

1.2 Problem Statement

In engineering areas such as aerospace, automotives, shipbuilding and medicine, it is difficult to develop a CAD model of an existing product that has a free-form surface or a sculptured surface (Yu, 2003). Application of the RE technology is to generate necessary CAD models of the existing product/part by capturing the surface. RE process in getting a CAD model consists of four main stages such as (1) part digitization – contact and non-contact, (2) data editing, (3) curve and surface generation and (4) CAD model construction. The successful of producing a prototype model is depends on all main stages and not only limited to certain stage. Most studies of RE undertaken are not concentrated on part digitization stage although it will influence the output of prototype. Researchers are not focused on gathering good raw data through digitization strategies.

Kruth & Kerstens (1998), Huang & Tai (2000) and Budak et al. (2005) used contact method (CMM) in their research and focused on second stages of RE process, pre-processing of data points measured from an existing object before B-spline curve fitting in improving the low quality of digitization results. Those researchers have focused on the data editing stage for good prototype results although they have gone through the part digitization stage. It is due to improper handle of part digitization strategies will lead to data uncertainties hence it is requires emphasizing on data editing stage.

In other way where much attention are to deal with redundant data elimination, Wang et al. (1999) and Xie et al. (2007) have concentrated on part digitization stage in order to achieved better 3D results by developed their own digitizing system. Wang et al. (1999) had introduced a system for design sculptured surfaces by four-axis non-contact scanning (which whole system that integrated of a PC-based XYZ table, a laser displacement meter (LDM), and a personal computer) while Xie et al. (2007) had proposed for a full field of view scanning system by composing of a CCD camera, a galvanometer and a laser projector. However, the studies in part digitizing process is limited to configuration of hardware and no digitizing parameters were highlighted. As a result, the accuracy of the system is relatively low when measuring parts with fine structures.

While another research by Feng (2005) was trying to skip data point pre-processing to express reverse engineering time by a methodology of internet-based reverse engineering approach to perform contact method CMM digitization process and creating a solid model that then transmitted via internet to rapid prototyping machine to produce a final part and also similar research by Lee and Woo (2000) in integration of reverse engineering using non-contact method 3D scanner that allows fabricating RP parts directly from geometric data. Those researchers are used different approach of part digitization which is contact and non-contact data capturing without stress on digitizing parameters involvement and eliminates the data editing stage to fasten RE process.

As the conclusion, even though many researches in reverse engineering applications show CAD model of an existing parts were successfully reconstructed by using CMM or 3D laser scanner, but the researches need additional task in editing stage such as developed extra programme to reduce noises and errors. However, additional task in editing stage can be eliminated if part digitization stage is carried out properly since surface measurement is the first priority in reverse engineering process. There are also none of the researches have been done in focusing to digitization methods based on contact and non-contact techniques.

1.3 Research Objectives

The objectives of the present research can be divided as the followings:

1. To evaluate the parameters and capabilities of contact and non-contact digitization methods.
2. To compare the quality of method used in re-engineering CAD models by using contact and non-contact methods.

1.4 Scope of Research

The scopes of the research are focusing to:

1. Digitization stage in producing CAD model for reverse engineering by implementation of two digitization method using contact and non-contact.
2. Generating of CAD model to compare the quality produced.

1.5 Thesis Layout

The thesis consists of five chapters. Chapter One gives an introduction of reverse engineering, methodology and reverse engineering process, problem statement, objective, scope and thesis layout. Chapter Two presents state-of-the art of RE, review of digitizing equipment using CMM and laser scanner for the free-form surfaces and design of experiment (DOE). Chapter Three describes the details of RE methodology, digitization methods, RE techniques approach involved in part digitization for contact and non-contact such as point to point scanning, line scanning, automated scanning and manual scanning by using CMM and 3D laser, data editing and CAD model construction for every technique used., experimental design, CAD/CAM system and also included about rapid prototyping machine used for model prototyping, The analysis of the results and discussions are discussed in Chapter Four. Finally, the thesis concluded with Chapter Five with a summary of research findings, the conclusion and future research recommendations.

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