View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Repository@USM

DEVELOPMENT OF REVERSE ENGINEERING SYSTEM FOR GENERATING 3D CAD BODY FROM 2D IMAGE

NUR ILHAM AMINULLAH BIN ABDULQAWI

UNIVERSITI SAINS MALAYSIA

2017

DEVELOPMENT OF REVERSE ENGINEERING SYSTEM FOR GENERATING 3D CAD BODY FROM 2D IMAGE

by

NUR ILHAM AMINULLAH BIN ABDULQAWI

Thesis submitted in fulfilment of the
requirements for the degree of
Master of Science

October 2017

ACKNOWLEDGEMENT

First and foremost, Alhamdulillah, all praises to the only one of All-compassionate and All-merciful for giving me the strength to conduct this research and to endure until the final stage of my Masters study. Special thanks and acknowledgements to my supervisor, Dr. Mohd Salman bin Abu Mansor as his guidance is very much appreciated and his advices had helped me a lot in completing this research. Thank you for the priceless knowledge and experience.

I would also like to extend my appreciations to the technical assistants and supports given by Mr Baharom, Mr Jamari and also Mr Azrul for providing great assistances in using the school's equipments and facilities during the research, especially with the 3D laser scanner in CNC laboratory.

Nevertheless, I would like to thank the group of my postgraduate friends around who they had cherished me a lot during the downs and ups along the journey.

Besides, special thanks to all my family members for their supports and being understanding towards myself.

Last but not least, thanks to the Ministry of Higher Education, Malaysia for providing tuition fee sponsor through MyMaster scheme.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	xi
LIST OF SYMBOLS	xii
ABSTRAK	xiv
ABSTRACT	xvi
CHAPTER ONE: INTRODUCTION	
1.0 Introduction	1
1.1 Research Background	1
1.2 Problem Statement	1
1.3 Objectives	3
1.4 Scope of Study	3
1.5 Research Approach	4
1.6 Thesis Organisation	4
CHAPTER TWO: LITERATURE REVIEW	
2.0 Chapter Overview	5
2.1 Reverse Engineering in Modern Manufacturing	5
2.2 New Generation of Manufacturing Industries	6
2.3 The Critical Aspects in Manufacturing: Cost, Quality and Lead Time	7
2.4 Data Acquisition Methods for Reverse Engineering	8
2.5 Scan-based and Vision-based Data Acquisition in Non-contact Reverse Engineering	9

2.6 Related Works on Image Processing and Data Segmentation 14

2.7 Related Works on Output Data Refining 16

2.8 Related Works on Surface Fitting for Structured Point Data 17

2.9 Chapter Summary 18

CHAPTER THREE: METHODOLOGY

3.0 Overview of Reverse Engineering System based on 2D Image 20

3.1 The Overall Process Flow 21

3.2 From 2D Digital Image into 3D Point Cloud 22

3.3 Point Cloud Refinement by Smoothening 38

3.4 Surface Reconstruction from Smoothened Points 40

3.5 Optional Volumetric Transformation 42

3.6 Methodology Summary 43

CHAPTER FOUR: IMPLEMENTATION AND RESULTS

4.0 Intermediate Results based on Test Objects 44

4.1 Implementation based on Actual Objects 48

4.2 The Results Visualisation 54

4.3 Benchmark with 3D Scanner for Comparison Analysis 61

4.3.1 Comparison on the Generated 3D Point Clouds 61

4.3.2 Comparison on the Generated Sheet bodies 70

4.4 The Volumetric Transformations 86

CHAPTER FIVE: DISCUSSIONS

5.0 Discussions based on the Research 88

5.1 Discussion on the 3D Point Clouds 88

5.1.1 Characteristic of the Point Clouds 88

5.2 Discussion on the 3D Sheet bodies 93

5.2.1 Characteristic of the Sheet bodies 94

5.2.2 Error for Generated Sheet bodies 98

5.3 Discussion on Absolute Heights Error for Gauge Block 99

CHAPTER SIX: CONCLUSION

6.0 Main Findings 101

6.1 Contributions of the Research 101

6.2 Limitations and Recommendations 102

REFERENCES 103

APPENDICES

Appendix A: Sheet Body Definition by ACIS's Topology

Appendix B: Experiment Results of Cylindrical Machining Workpiece as Standard

Appendix C: Experiment Results of Inclining Flat Surface Plate

Appendix D: Numerical data of mean and standard deviation for 2D plots

Appendix E: Numerical data of mean and standard deviation for gauge block

LIST OF PUBLICATIONS

LIST OF TABLES

		Page
Table 2.1	Summary of all reviewed data acquiring methods for reverse engineering.	11
Table 4.1	Nearest neighbour distance for 3D coordinates and errors for brush cover.	64
Table 4.2	Nearest neighbour distance for 3D coordinates and errors for mini spoon.	65
Table 4.3	Nearest neighbour distance for 3D coordinates and errors for calculator casing.	66
Table 4.4	Nearest neighbour distance for 3D coordinates and errors for toy pistol.	67
Table 4.5	Nearest neighbour distance for 3D coordinates and errors for door handle.	68
Table 4.6	Nearest neighbour distance for 3D coordinates and errors for gauge block.	69
Table 4.7	The average errors and standard deviations of all objects.	81
Table 4.8	The summary of sampling from planar surface and background surface.	86
Table 4.9	The volumetric transformation successfulness diagram based on tested objects.	87
Table 5.1	The optimum number of points by ratio of the proposed system compared to 3D scanner.	93

LIST OF FIGURES

		Page
Figure 3.1	The illustrated systematic approach that consists of two phases	20
Figure 3.2	Overall system's process flow chart	21
Figure 3.3	The triangle model used in this framework sliced from the HSV hex-cone model from Jack (2008)	23
Figure 3.4	The cylindrical workpiece as standard (a) the specimen, (b) the 2D image, (c) raw HSV conversion data and (d) the sectioned view of the distributed data	24
Figure 3.5	The imaginary path of increasing h function depending on V based on the triangle sliced of HSV hex-cone model	26
Figure 3.6	The strength of tone down comparison for *ln* and *ln(sin)*	27
Figure 3.7	The characteristics of exponential and natural logarithm functions	28
Figure 3.8	The inclining profile setup for testing the distorted region using flat surface object	29
Figure 3.9	The concatenation of a sample 5 x 5 matrix and the gridded results are combined with z values according to ascending numbers	31
Figure 3.10	The illustration of background non-zero adjustment and logic filtering to combine the best result using a test image with an object in the middle of black background.	33
Figure 3.11	The process of determining the deviation (a) to create a cylindrical geometry of diameter 26mm, (b) convert to CATIA format, (c) deviation analysis and (d) distribution plot	34
Figure 3.12	The Z data yielding 0.02 mm as 1 point distance space based on the cylindrical profile as calibration reference.	36
Figure 3.13	The process to obtain point distance of X and Y coordinate space (a) export to asc format, (b) convert all Z values into a same level of value and (c) import back into CATIA for measurement.	37
Figure 3.14	The key components that made up a net-wired surface from point cloud	41
Figure 3.15	Options for creating solid volumes from sheet body or bodies generated by the system	43

Figure 4.1	Tested results based on cylindrical machining workpiece as standard (a) the distributed pattern values before applying 'ln(sin)' function, and (b) the distributed pattern values after applying 'ln(sin)' function.	44
Figure 4.2	The cross-sectioned view with sliced out 2D plots on x-z axis at y = 140,150,160,170,180,190. (a) before applying '*ln(sin)*' function and (b) after applying '*ln(sin)*' function	45
Figure 4.3	The inclining flat surface object tested results showing distorted regions for various angle of (a) $\sin^{-1}(20/140)$, (b) $\sin^{-1}(20/130)$, (c) $\sin^{-1}(20/120)$, (d) $\sin^{-1}(20/110)$ and (e) $\sin^{-1}(20/100)$.	46
Figure 4.4	The 2D plots of before (left) and after (right) of applying *ln(sin)* function of (a) $\sin^{-1}(20/140)$, (b) $\sin^{-1}(20/130)$, (c) $\sin^{-1}(20/120)$, (d) $\sin^{-1}(20/110)$ and (e) $\sin^{-1}(20/100)$.	47
Figure 4.5	The setup of the system (a) schematic diagram, (b) using loose setup with retort stand (c) using compact setup with 20cm x 20cm x 30cm box build assembly.	50
Figure 4.6	The specimen or known as brush cover of Kasei's grass cutter and its detailed implementation for 3D point cloud	51
Figure 4.7	The compatible CAD software for generating .SAT file format from (a) Scheme AIDE Hoops to (b) SolidWorks	52
Figure 4.8	The volumetric transformation of 3D sheet body into enclosed volume, thickened volume using +1.0 mm thickness or sandwiched volume	53
Figure 4.9	The optional formation of volumetric bodies of (a) enclosed volume, (b) thickened volume and (c) sandwiched volume of two 3D sheet bodies	54
Figure 4.10	The specimen of brush cover (a) actual part, (b) selected view in 2D image, (c) generated 3D point cloud and (d) generated sheet body	55
Figure 4.11	The specimen of mini spoon (a) actual part, (b) selected view in 2D image, (c) generated 3D point cloud and (d) generated sheet body	56
Figure 4.12	The specimen of calculator casing (a) actual part, (b) selected view in 2D image, (c) generated 3D point cloud and (d) generated sheet body	57
Figure 4.13	The specimen of toy pistol (a) actual part, (b) selected view in 2D image, (c) generated 3D point cloud and (d) generated sheet body	58
Figure 4.14	The specimen of door handle (a) actual part, (b) selected view in 2D image, (c) generated 3D point cloud and (d) generated sheet body	59
Figure 4.15	The 20 mm gauge block (a) actual part, (b) selected view in 2D image, (c) generated 3D point cloud and (d) generated sheet body	60
Figure 4.16	The NEXTENGINE 3D scanner (HD) used for benchmarking results of the vision-based reverse engineering from 2D digital image system	61

Figure 4.17	The overlapping for 3D point clouds, firstly (a) perform 3D laser scan on the specimen follow by trimming the excess, (b) input of the 2D image generated point cloud data, and (c) align of both sets of point cloud data by translating the laser scanned data to match its comparing data based on the calculated centroids.	62
Figure 4.18	The selected points of A-J from brush cover where the laser scanned data were available	63
Figure 4.19	The selected points of K-T from mini spoon where the laser scanned data were available	65
Figure 4.20	The selected points of U-Z and AA-AD from calculator casing where the laser scanned data were available	66
Figure 4.21	The selected points of AE-AN from toy pistol where the laser scanned data were available	67
Figure 4.22	The selected points of AO-AX from door handle where the laser scanned data were available	68
Figure 4.23	The selected points of AY-BH from door handle where the laser scanned data were available	69
Figure 4.24	The surfaces comparison by first (a) selecting a cross-section, followed by (b) cutting at the cross section and (c) recording the relative height of every 5mm in 2D plot.	70
Figure 4.25	The equally spaced selected cross-sectioned profiles of (a) A-E for brush cover, (b) F-H for mini spoon, (c) I-L for calculator casing, (d) M-R for toy pistol, (e) S-V for door handle and (f) W-Y for block gauge	71
Figure 4.26	The 2D plot for cross-sectioned for (a) profile A, (b) profile B, (c) profile C, (d) profile D and (e) profile E.	72
Figure 4.29	The 2D plot for cross-sectioned for (a) profile M, (b) profile N, (c) profile O and (d) profile P.	75
Figure 4.31	The 2D plot for cross-sectioned for (a) profile S, (b) profile T, (c) profile U and (d) profile V.	77
Figure 4.32	The 2D plot for cross-sectioned for (a) profile W, (b) profile X , (c) profile Y and (d) profile Z	78
Figure 4.33	The average error and standard deviation range for brush cover	79
Figure 4.35	The average error and standard deviation range for calculator casing	79
Figure 4.36	The average error and standard deviation range for toy pistol	80
Figure 4.37	The average error and standard deviation range for door handle	80

Figure 4.38	The average error and standard deviation range for gauge block	80
Figure 4.39	The planar surface and background scene as one sheet body	82
Figure 4.40	Measure height difference using CATIA software	82
Figure 4.41	The planar surface sampling method by (a) sectioning into equal interval vertically and horizontally, (b) one of the sections in horizontal direction, (c) the section as 3D line and insertion of points using Points Repetition function, and (d) the sampling points tabulated using Automatic Table function.	84
Figure 4.40	The background surface being sectioned equally into 21 horizontal sections and 28 vertical sections for sampling.	85
Figure 5.1	The miss-scanned area on the point cloud generated by 3D laser scanner	89
Figure 5.2	The mechanism of (a) vision data acquisition method versus (b) 3D laser scanning method	90
Figure 5.3	The results of scanning complete rotation and miss scanned areas still exist	91
Figure 5.4	The result of (a) vision data with higher resolution and its corresponding point cloud having dense arrangement (b) vision data with lower resolution and its corresponding point cloud having sparser arrangement	92
Figure 5.5	The differences of surfacing method (a) net wiring, (b) mesh and (c) mesh with increased number of points	95
Figure 5.6	Meshes as planar combination with of density ratio of about 1:4 to net wiring intervals at 0.25 mm x 0.25 mm	96
Figure 5.7	The formation of 3D scanner's mesh surface and sheet’s net wiring surface	97
Figure 5.8	(a) Visualisation of net wiring representation and (b) regular fitted surface representation	98
Figure 5.9	Evidence of (a) background noise visualised through sheet body and (b) metal oxidation found on the gauge block	99
Figure 5.10	The ideal scenario (left) versus the actual scenario (right) for the system	100

LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
ACIS	Alan Charles Ian's system
AIDE	Alan Charles Ian's interface driver extension
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
DDR3	Double Data Rate Type Three
GMA	Graphics Media Accelerator
HD	High-definition
HSV	Hue, saturation and value
IES	Illuminating Engineering Society
NPD	New product development
NURBS	Non uniform rational B-spline
RGB	Red, green and blue
SFS	Shape from shading
USB	Universal Serial Bus
XYZ	Coordinates in x-direction, y-direction and z-direction format

LIST OF SYMBOLS

^	Smoothened parameter
a	The starting row number of horizontal B-spline
b	Constant for column number when row number changes incrementally
c	The decreasing column number for constant row number
Ct	Denotation for centroid
D	Overall sizing of the point cloud
d	Depth variation
dn	Distance of the targeted point to next point
f	Height factor
h	Height variation distribution
h_i	Starting point in the height variation distribution
h_o	Maximum point in the height variation distribution
k	The number of control points including the last imaginary point in horizontal direction
l	The number of control points including the last imaginary point in vertical direction
m	Maximum row number of the matrix
N	Maximum number of the matrix
n	Maximum column number of the matrix
PC	Point cloud
$PC_{refined}$	Refined point cloud
PC_{final}	Final point cloud
r	Defined constant in tricube weight function
T	Transpose symbol of the matrix

t	Total point number
V	Value from the HSV triangle slice
w_i	Weight factor i^{th} position as refers the next neighbour point
x	The x-coordinate
y	The y-coordinate
z	The z-coordinate
z_i	The z-coordinate at i^{th} position as refers the next neighbour point
$\hat{z}_i$	The smoothened z-coordinate at i^{th} position as refers the next neighbour point
α	Constant of the second degree polynomial
β	Second coefficient of the second degree polynomial
γ	Leading coefficient of the second degree polynomial
σ	Standard deviation

PEMBANGUNAN SISTEM KEJURUTERAAN BALIKAN BAGI PENGHASILAN BADAN CAD 3D DARIPADA IMEJ 2D

ABSTRAK

Kejuruteraan balikan mempunyai potensi untuk diintegrasikan ke dalam aplikasi-aplikasi pembuatan secara jarak jauh berasaskan kepada kemudahan teknologi internet yang ada pada hari ini. Namum begitu, kejuruteraan balikan yang menggunakan alat berasaskan imbasan memerlukan objek nyata dan alat perolehan data seperti alat imbasan 3D untuk berada di lokasi yang sama, melainkan adanya teknologi yang mampu memindahkan objek nyata melalui alam siber. Kejuruteraan balikan berdasarkan imej 2D merupakan salah satu cara penyelesaian yang berpotensi kerana imej 2D boleh dipindahkan melalui alam siber. Akan tetapi cara melakukan kejuruteraan balikan dengan imej 2D ini mestilah menghasilkan kejituan dimensi yang tinggi ataupun hampir sama dengan objek nyata yang asal, agar cara tersebut kekal relavan dalam industri pembuatan. Penyelidikan ini menumpukan kepada pembangunan sebuah sistem kejuruteraan balikan yang berdasarkan imej 2D, bersama-sama dengan teknik-teknik unik seperti pengasingkan data, pemprosesan imej secara berkomputer dan juga penambahbaikan data yang dimasukkan ke dalam sistem tersebut. Kemudian, pengesahan terhadap sistem dilakukan berdasarkan perlaksanaan terhadap objek-objek yang nyata, dan kejituan dimensi dari setiap hasil keputusan akan dianalisa secara berangka bagi perbincangan selanjutnya. Keputusan menunjukkan bahawa kejituaan dimensi menggunakan cara kejuruteraan balikan berdasarkan imej 2D adalah seakan menyerupai objek asal dengan mempunyai kejituan yang kurang daripada 0.4mm. Sistem yang dicadangkan ini akan dijadikan sebagai titik permulaan bagi kejuruteraan balikan secara jarak jauh, sekaligus membolehkan sistem ini berpotensi untuk mengantikan pengimbas laser 3D jika dalam keadaan yang terpaksa, dimana pengimbas laser 3D tidak terdapat di kawasan yang terdekat. Keaslian penyelidikan ini ialah pada sistemnya dan kaedah yang digunakan untuk menghasilkan keputusan yang berbentuk 3D daripada data berbentuk 2D. Sistem yang

dicadangkan ini bukan sahaja boleh digunakan dalam aplikasi kejuruteraan balikan jarak jauh, malah sistem ini turut bernilai bagi aplikasi kejuruteraan balikan yang berkos rendah.

DEVELOPMENT OF REVERSE ENGINEERING SYSTEM FOR GENERATING 3D CAD BODY FROM 2D IMAGE

ABSTRACT

Reverse engineering has the potential to be integrated into remote manufacturing applications, based on the internet technology today. However, reverse engineering using common scan-based device requires the physical object and the data acquisition device such as 3D laser scanner to co-exist at the same location, unless the physical object is made transferable within the cyber space. Reverse engineering based on 2D image is one of the potential solution for implementing remote reverse engineering process because 2D image is transferable with cyber space. However, reverse engineering based on 2D image must produce high dimensional accuracy outputs as exact as possible similar to the actual physical object in order to be relevant to the manufacturing industry. This research focused on developing a system for implementing reverse engineering based on 2D image, together with some unique techniques such as data segmentation, computer image processing methods and data refinement that were included into the system. Then, verification on the system was performed based on the implementation on real case objects, and the dimensional accuracy of each produced result was numerically analysed for further discussions. The results showed that reverse engineering based on 2D image is possible to be similar to the actual objects at accuracy level of less than 0.4mm. The proposed system will be the starting point for remote reverse engineering application, and has the potential to be an alternative solution whenever there is no data acquisition device such as 3D scanner available on the spot. The originality of this research is on the system and methodology used for producing 3D results from 2D data. The proposed system is not just suitable for remote reverse engineering application, but also is valuable for low cost reverse engineering application as well.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This chapter begins with the basic background of the use of reverse engineering in manufacturing process. Next is the phenomenon of globalisation in manufacturing industries alongside with the growing usage of cyber technology within manufacturing industries that stimulate the intention of conducting this research.

1.1 Research Background

Reverse engineering is commonly being practiced in manufacturing industries as the process of retrieving design details from an existing physical object according to Mavromihales et al. (2003). The retrieved design details can be used as reference to generate new designs for manufacture components especially in new product design and development stages. The most common device used in retrieving design details is the three dimensional (3D) laser scanner. This is because the 3D laser scanner is commercially available in the open market. Besides, 3D laser scanner gains popularity among the users is due to its advantages of having non-contact mechanism. Compared to other devices that have contact mechanism, the risk of damaging the physical part is lower in non-contact devices.

Manufacturing industry on the other hand is currently experiencing revolution. Alongside with cyber technology, manufacturing industry is moving towards cyber manufacturing where data and information are transferable within cyber space to save time, cost and space (Wang et al., 2016). Therefore, reverse engineering process should also be included into this modern manufacturing environment in order to stay relevant in the industry.

1.2 Problem Statement

3D laser scanners in the industry today are designed for acquiring surface detail from the physical objects. However 3D scanner working mechanism is totally dependent on the

availability of the physical object. Without physical object at the same location as the 3D laser scanner, it will be very problematic to perform the data acquisition process remotely with 3D laser scanner.

Besides, 3D laser scanners in the market nowadays are still generally expensive and require extensive maintenance cost as mentioned by Campanelli et al. (2016). This causes reverse engineering process to be only accessible by certain manufacturers of high revenue businesses. Average manufacturers usually will opt out from reverse engineering process since the cost of purchase and cost for skilled labour towards the 3D laser scanner will burden them. Due to the fact that remote application of reverse engineering using 3D laser scanner is impossible and the 3D laser scanner is consuming high cost for average manufacturers even for local application, these collective issues should be overcame with an alternative, where the reverse engineering is performed without using any 3D laser scanner.

On the other hand, faster product launch in market is often a requirement in new product design and development, and reverse engineering is also part of the product design and development process whenever old existing products are used as references demonstrated by Chang and Park (2008). It will be another issue when new product launch is taking longer time due to remote working locations especially in using 3D laser scanner since transporting the existing part towards the 3D scanner will consume time. Similarly the vice versa of transporting 3D scanner towards the existing part will consume the time as well.

To overcome these collective issues, reverse engineering based on two dimensional (2D) digital image will be the solution since 2D digital image appears to be in the form of virtual data which can be transferred through cyber space. However the produced results via this method must at least preserve the basic shapes of the physical objects and also to achieve acceptable dimensional accuracy.

1.3 Objectives

This research's main objective is to develop a system for reverse engineering process that based on 2D digital image as input. Besides, this research also aims to accomplish the following specific objectives:

a) To develop an extraction method for obtaining useful information from 2D digital images for conversion process into 3D point clouds by studying the information found in 2D digital images.
b) To develop a specific refining method for improving the accurateness of the 3D shapes/features representation by studying the structure of the 3D point clouds obtained from 2D images.
c) To develop a simple surfacing method to form sheet bodies as 3D Computer Aided Design (CAD) format from the after refined point clouds by studying the structure of refined point clouds.
d) To test the developed methodology for verifying the system's accuracy.

1.4 Scope of Study

This study will include scopes that are related to reverse engineering process based on 2D digital image, also known as vision-based reverse engineering. Scopes included are data acquisition from 2D digital images, transforming 2D data into useful 3D point clouds, point clouds refinement, and also surface fitting for creating 3D sheet bodies in CAD format from refined point clouds.

However, the study of reverse engineering that is based on 3D scanner or other data acquisition device will not be included. The accuracy problem in 3D scanner will be mentioned but is not part of the research. Registration from multiple orientations in reverse engineering also is not part of the research.

1.5 Research Approach

This research used platform of computer programming in order to extract data from 2D images. From the data extracted, various approaches are used for processing the data and then producing the intended final outputs.

Besides, the outputs are benchmarked with another system, the 3D laser scanner's system for accuracy comparison.

1.6 Thesis Organisation

This thesis starts with the introduction in Chapter 1 that links to the motive of conducting the research. Chapter 2 presents literature reviews that support the intended motive.

After literature reviews, methodology of achieving the desired objectives will be described in details in Chapter 3. Following in Chapter 4 are the implementation of methodology and its results to demonstrate the effectiveness of the methodology. Together with the obtained results, discussions will be presented graphically with explanations in Chapter 5.

The thesis will end with a conclusion in Chapter 6 that describes the outcomes of this research. Alongside, some unanswered questions which are related to this current research will be mentioned as future works.

CHAPTER TWO

LITERATURE REVIEW

2.0 Chapter Overview

In this chapter, past research related to reverse engineering methods and its applications towards modern manufacturing industry are reviewed. More emphasis is given to the works published in field areas related to manufacturing and industrial engineering. The reviews are divided into the following 8 sub areas: reverse engineering in modern manufacturing, the new generation of manufacturing industries, relation between manufacturing's aspects of cost versus quality versus lead time, data acquisition systems for reverse engineering, scan-based versus vision-based differences, image processing with data segmentation for vision-based data acquisition, data refining for 3D point cloud and surface fitting for structured point cloud which lead towards to this research. A summary highlighting the main motivation towards this research and the knowledge gap is provided at the end to the chapter.

2.1 Reverse Engineering in Modern Manufacturing

The main component of this study is about reverse engineering in modern manufacturing industries. According to Javidrad and Rahmati (2009), modern reverse engineering is not just about the process of duplicating virtual 3D CAD model from physical objects. Modern reverse engineering, however, is the important sub-process for the overall re-manufacturing process where sometimes product redesign are necessary for fitting in certain engineering considerations. Most manufacturers make use of reverse engineering for quick product redesign and redevelopment purposes based on available information extracted from the product as pointed out by Wang et al. (2004). During the product redesign and redevelopment activities, the extracted object's details are used as part of the design and planning stage in manufacturing process as proven by Sokovic and Kopac (2006). Hence, those relevant value engineering considerations including product features modification and

tool reselection, should be applied concurrently to the product redesign process as recommended by Du et al. (2013) and Smith et al. (2012).

Since the applications of reverse engineering had been redefined as using available product references to create better products, this means that reverse engineering is rather a copy and fabrication process. In many circumstances, there should be design changes and optimisations involve based on professional assessments along the process of reverse engineering. Hence, reverse engineering should not be mistaken as reduplication of a product especially in modern manufacturing. Instead reverse engineering should be defined as the supporting tool which provides references for product redesign and redevelopment activities.

2.2 New Generation of Manufacturing Industries

Manufacturing industries are constantly evolving and new technologies are also constantly being adopted in the manufacturing industries for better civilisation benefits. It all started from the history of the first industry revolution which is about the utilisation of mechanical systems such as steam engines in manufacturing industries during the 18th century (Bruland and Smith, 2013; Spear, 2008). Followed by is the second industrial revolution when electricity and machinery took place to enable mass production (Goldin and Katz, 1998; Winder, 2002). Then the third revolution is robotics-automation systems utilisation in manufacturing industries (Dhinesh Kumar et al., 2005; Torii, 1989). And until recently, it comes to the fourth revolution where manufacturing industries rely on internet-of-things and cyber-physical systems where many related topics are recently studied by researchers (Huang et al., 2015; Segura Velandia et al., 2016; Wang et al., 2016; Wu et al., 2013; Yu et al., 2015), in order to maximize the production's efficiency in term of cost, time and space, plus for better control on production quality. This fourth industrial revolution is currently still in on-going mode. There are still many topics of interest yet to be explored alongside with major innovative developments need to be taken place.

Reverse engineering is one of the topics of interest yet to be explored in the fourth industrial revolution. If there is a reverse engineering system that can be integrated into this current cyber manufacturing environment, more time and cost saving in production can be achieved especially in remote working conditions. This type of remote reverse engineering system will be useful during the product design and planning stage, especially in this new age manufacturing industry.

2.3 The Critical Aspects in Manufacturing: Cost, Quality and Lead Time

For industrial manufacturers, cost saving and time reduction in product development is crucial for maximising profit margin (Cankurtaran et al., 2013; Johnson and Kirchain, 2011; Marion and Meyer, 2011). Even though most manufacturers understand that these three factors of product's quality, cost and cycle time are usually going to trade-off to each other Everaert and Bruggeman (2002), average manufacturers tend to prioritise cycle time at first especially during new product development (NPD) stage, due to marketing strategies.

In fact, reverse engineering is necessary for shortening the time of NPD whenever new design derived from existing products is required as suggested by Hsiao and Chuang (2003). However, most manufacturers will avoid investing on high cost equipments especially during the design and planning stage, unless they are manufacturers of high revenue businesses. Because of the cost factor, reverse engineering systems with high accuracy and high speed performance will usually not be the option for average manufacturers.

Regardless of what reverse engineering approach is being used, the dimensional accuracy requirement for product design is supposed to be less tight compare to the requirement of direct copy and remanufacture the existing product. It is because the design details of reverse engineering are supposed to be modifiable through common CAD/CAM/CAE software for further enhancement of the product's function and the