COMPREHENSIVE STUDY ON 3D SCANNER METHOD TO CONVERT CLOUD DATA TO SURFACE MODELING

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY)

2022

Faculty of Mechanical and Manufacturing Engineering Technology

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This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I hereby, declare this report entitled "Comprehensive Study On 3D Scanner Method to Convert Cloud Data to Surface Modelling," is the result of my own study, with the exception of the references given. The Choose an item. has not been approved for any degree and is not being considered for any other degree at the same time.

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Date : 17 JANUARY 2022

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours. The member of the supervisory is as follow:

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DEDICATION

Alhamdulilah, thanks be to Allah for providing me with the strength, direction, and knowledge I needed to finish my study. I dedicate my thesis to my loving parents for their unwavering moral support, as well as Fauzi bin Paijan and Hafizah binti Abu Bakar for meeting all of my needs while compiling this thesis from start to finish. Finally, many thanks to my supervisor, Mr Mohammad Rafi Bin Omar, for his help and advice in finishing my thesis.

ABSTRACT

A 3D scanner is a device that collects real-life data about the form and appearance of an object or environment to the collected data can be used to generate three-dimensional computer models. Following that, a common issue discovered through this research is that 3D scanning is a promising option, but it is unclear how these new technologies compare to traditional ways. An experimental study is being conducted to investigate the conversion of data point clouds from a 3D scanner to CAD data with a variety of shapes, such as simple geometrical shapes, and complex shapes. The objective of this experiment is to compare a few different software designs to optimum method duration time for conversion cloud data. The T-Scan Lv system is utilised as a laser scanning during the 3D scanning procedure. Three trials of each model sample shape are use in this experiment method. The software is used to modify the point cloud data to surface modelling is PolyWorks and Catia. The result collected based on the scanning duration, editing cloud data duration and mean of standard deviation in percentage. From the overall result, the most accuracy software are used to editing cloud data to surface modelling is complex shape for PolyWorks software where the mean of standard deviation is 96.78% while for Catia software is square shape which is the mean of standard deviation is 96.14%. Finally, every method of modifying cloud data utilising the greatest software has been studied.

ABSTRAK

Pengimbas 3D ialah peranti yang mengumpul data kehidupan sebenar tentang bentuk dan rupa objek atau persekitaran kepada data yang dikumpul boleh digunakan untuk menjana model komputer tiga dimensi. Berikutan itu, isu biasa yang ditemui melalui penyelidikan ini ialah pengimbasan 3D merupakan pilihan yang menjanjikan, tetapi tidak jelas bagaimana teknologi baharu ini dibandingkan dengan cara tradisional. Kajian eksperimen sedang dijalankan untuk menyiasat penukaran *point cloud* data daripada pengimbas 3D kepada data CAD dengan pelbagai bentuk, seperti bentuk geometri mudah dan bentuk kompleks. Objektif percubaan ini adalah untuk membandingkan beberapa reka bentuk perisian yang berbeza dengan masa tempoh kaedah optimum untuk penukaran data awan. Sistem T-Scan Lv digunakan sebagai pengimbasan laser semasa prosedur pengimbasan 3D. Tiga percubaan bagi setiap bentuk sampel model digunakan dalam kaedah eksperimen ini. Perisian yang digunakan untuk mengubah suai data *point cloud* kepada pemodelan permukaan ialah PolyWorks dan Catia. Hasil yang dikumpul berdasarkan tempoh pengimbasan, pengeditan tempoh *cloud data* dan purata sisihan piawai dalam peratusan. Daripada hasil keseluruhan, perisian ketepatan yang paling banyak digunakan untuk menyunting *cloud data* ke pemodelan permukaan ialah bentuk kompleks bagi perisian PolyWorks di mana min sisihan piawai ialah 96.78% manakala bagi perisian Catia adalah bentuk segi empat sama iaitu min sisihan piawai ialah 96.14%. Akhir sekali, setiap kaedah mengubah suai *cloud data* menggunakan perisian terhebat telah dikaji.

ACKNOWLEDGEMENTS

Alhamdulillah’s, I am finally completing this bachelor’s degree Project thanks to Allah SWT for His authority and blessing. I thank my advisor, Mr. Mohammad Rafi Bin Omar, for his support, and guidance during course of this endeavour. I thank him deeply. His advice has helped me write and accomplish this project research all the time. I could not have imagined a better study consultant.

All lecturers are thanked. During this semester, I learn most of theory and skills. A million of them apologise for the poor behaviour and unfavourable talk during the project. My wonderful family thanks a million for supporting me. I cannot find the words to convey my thankfulness and confidence for our capacity to succeed correct.

Thanks a million, to my delightful family for supporting me. I cannot find the right term for your support and trust in our capacity to succeed my appreciation. I would want to thank all my friends for their advice and support. I appreciate the support you have provided to complete the thesis for your thoughts and information. Finally, I would want to thank everyone engaged in my project, either directly or not. Your compassion I'm sure not to forget, and only Allah can repay all of you. Thank you very much.

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CHAPTER 1

INTRODUCTION

An overview of the 3D scanning method and data cloud countermeasure analysis will be provided for this chapter. The study will also discuss the fundamental idea, problem statement, objective, and goal. The structure of the report is described below.

1.1 Overview

Technologies integrates engineering and production technology for machinery production in industrial technology. Technology also facilitates and facilitates the industrial process. With the development of modern technology, technology has evolved drastically. Many burdens have been raised in human life with modern technologies. Today, several sophisticated technologies are employed in the manufacturing sector. 3D scanner, SLS, 3D printing and other technology for example.

A new way of assessing the surface of complicated objects or objects is by using 3D scanning technology. The 3D scanner generates an object's surface data "point cloud." In other words, a 3D scanner can capture the exact size and shape of physical objects as a 3D digital representation in the computer world. 3D scanning can measure objects in fine detail and record free-form forms such that highly accurate point clouds are quickly generated. 3D laser scanning is ideal for measuring and inspecting curved surfaces and complicated geometries that require a large quantity of data to be precise and insufficient in traditional measurement methods or a touch probe application.

3D scanning technology can relate to the reverse engineering process for product innovation design and 3D printing technology. This technology can be used to combining 3D scanning and reverse engineering technology. application of 3D scanning in RE process involves three main steps: (1) scanning, (2) point processing, and (3) application specific geometric model development. By reverse engineering, data are obtained, 3D scan technologies are used to produce a point cloud of surface object data. Point clouds are produced with 3D scanners or a photogrammetric program. That software measures many points on the outside surfaces. Point clouds are usually generated by 3D scanners or software that measure many points on the exterior surfaces of things surrounding them. From the output point cloud data many purposes are used including to create 3D CAD model or convert the point cloud data to engineering design software such as PolyWorks and CATIA.

The design is generally carried out by the CAD software designer, with a long cycle time and low efficiency that cannot match the demand of the market. Three-dimensional printing technologies can cut the production test cycle of new items and based on existing technologies, reverse engineering can copy and rebuild products and so shorten the design cycle. On this fundamental level, the study here proposes using a 3D scanning method to compare which one method of software, like CATIA and PolyWorks, easy to use to redesign the shape and compare the amount of time necessary to redesign the software. In this project, which is complex in form and geometry, there are two concept forms we chose. The outcome will be that the point nude will be converted into CAD software and that the object will be reshaped using CATIA or PolyWorks.

1.2 Problem Statement

In today's heavily competitive global market, manufacturers always seek new ways of reducing the time required to sell a new product. Rapid product developments (RPD) mean innovative technologies and processes that support manufacturers and designers to satisfy the requirements of shorter product development times. This means rapid product development. However, fewer studies have been carried out on the use of a 3D scanner to scan the geometric forms and complex forms of the data in a cloud.

Point cloud object classification, which is a classical and critical problem in computer graphics and computer vision fields, aims to identify the categories of different point cloud objects (Deng, 2022).

Surface modelling technology, which is an intrinsically challenging procedure in which each face or form is built from splines and unique sketches and geometry sets, is historically used to construct sophisticated objects. If smooth transitions between faces are required, each surface must work independently, as well as the transition (whether tangency or continuous curvature) (*DEVELOP3D*,2012).

Following that, a common issue discovered through this research is that 3D scanning is a promising option, but it is unclear how these new technologies compare to traditional ways. To fulfil this duty, early scanners used lights, cameras, and projectors (Farhan, 2021).

1.3 Objective

The main aim of this project to Comprehensive study on 3D Scanner Method to convert Cloud Data to Surface Modelling are:

a) To study the method conversion data point cloud data from 3D scanner to CAD data.

b) To scan cloud data and analyse geometry shape and complex shape by using 3D scanner.

c) To analyse for further investigations between a few designs software and compare the optimum method duration time for conversion cloud data.

1.4 Scope

The implantation of "Convert Cloud Data from 3D scanner by reverse engineering method" project converging into:

a) Develop of a 3D scanner component with complex internal features is 3D scanned and the point cloud is optimized before different surface modelling techniques are tested.

b) Application of 3D scanner type T-TRACK LV to scan geometry and complex shape and collect the cloud data.

c) Application of CATIA and PolyWorks software in design and choose the best method duration time for conversion cloud data.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss on the 3D scanner with reverse engineering to collect data from points. The general 3D scan overview, reverse engineering used, software development, comparative data also are shown to obtain the results set out in the research objectives. Figure 2.1 depicts the progression of the literary evaluation.

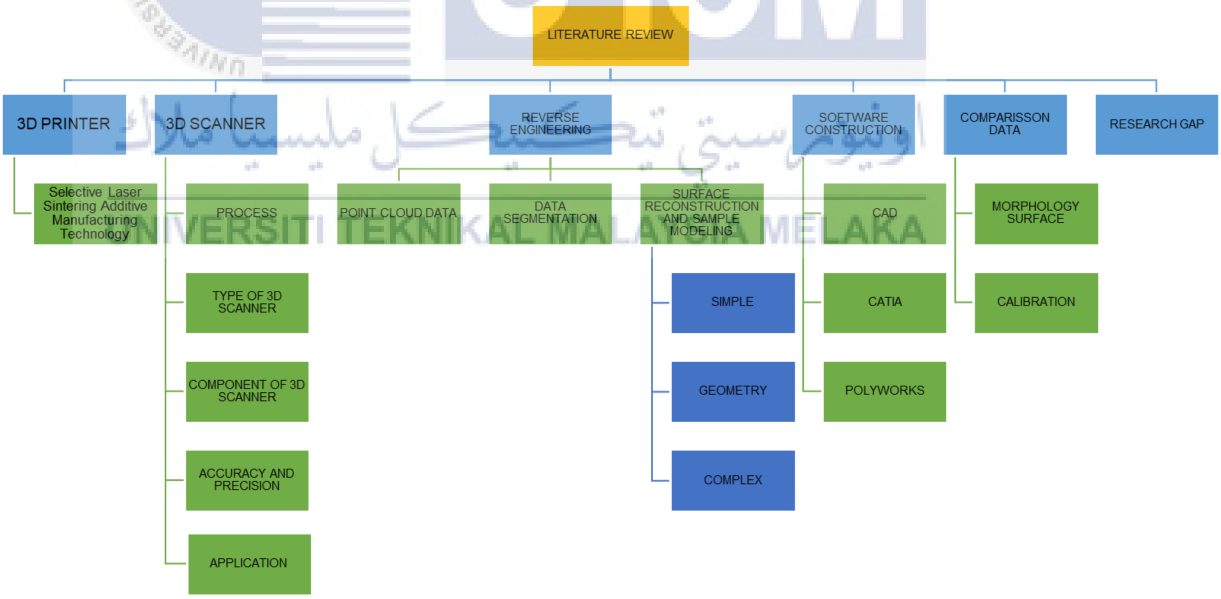

Figure 2. 1 Flow Chart of Literature review

2.2 General Overview of 3D Printer

Selective Laser Sintering Additive Manufacturing Technology (SLS) method. Selective Laser Sintering is an additive method that facilitates the manufacture of 3D things by melting a powdered material layer by layer using a laser SLS uses a CO2 laser as the heat source to fuse the powders under pressure -free conditions (Yan., 2019). SLS technology is one of the most promising advances in 3D printing due to the high complexity of parts it can form short manufacturing cycle, low cost, and wide range of materials it is compatible with. SLS production casting moulds, sand moulds (core), injection moulds with conformal cooling channels, and fast prototyping of ceramic and plastic functional components are typical examples of SLS technology. It is already widely utilised in aviation, aerospace, medicine, equipment, and a variety of other sectors ('Selective Laser Sintering Additive Manufacturing Technology', 2021). The proses of Selective Laser Sintering Process Excessive power beam laser is used to induce fusion of the powdered raw powder.

Currently, many 3D printed products have been produced; however, there is a gap between the physical qualities and surface morphology of the printed object. These methods have become more efficient, less expensive, more cost-effective, sophisticated, and higher in resolution and quality. Selective Laser Sintering is used to create objects with no supports; the design options are nearly infinite. During selective laser sintering, the particle coalescence of a powdered aggregate by diffusion is accomplished by firing at an elevated temperature and, in the other hand, during selective laser melting, the powder is transformed from solid phase into a liquid upon heating.

2.2.1 Proses

There are a few processes are involved in 3D printer process which is from the printing process until the post processing. Figure 2.2 show the Schematic of the selective laser sintering process.

1) **Printing:** The powder is applied in a thin layer on a platform within the build chamber. The printer preheats the powder to a temperature just below the raw material's melting point, making it simpler for the laser to raise the temperature of portions of the powder bed as it traces the model to solidify a component. The laser scans a cross-section of the 3D model, heating the powder to just below or just at the material's melting point. This mechanically fuses the particles together to form a single solid component. The unfused powder acts as a support framework for the component during printing, eliminating the need for separate support structures. The platform is then lowered into the build chamber by one layer, generally between 50 and 200 microns, and the procedure is repeated for each layer until the pieces are complete.
2) **Cooling:** After printing, the build chamber should be allowed to cool slightly inside the print enclosure and then outside the printer to provide good mechanical qualities and to avoid warping in components.
3) **Post-processing:** removing the final pieces from the build chamber, separating them, and cleaning them of excess powder. The powder may be recycled, and the printed pieces can be further treated using media blasting or media tumbling.

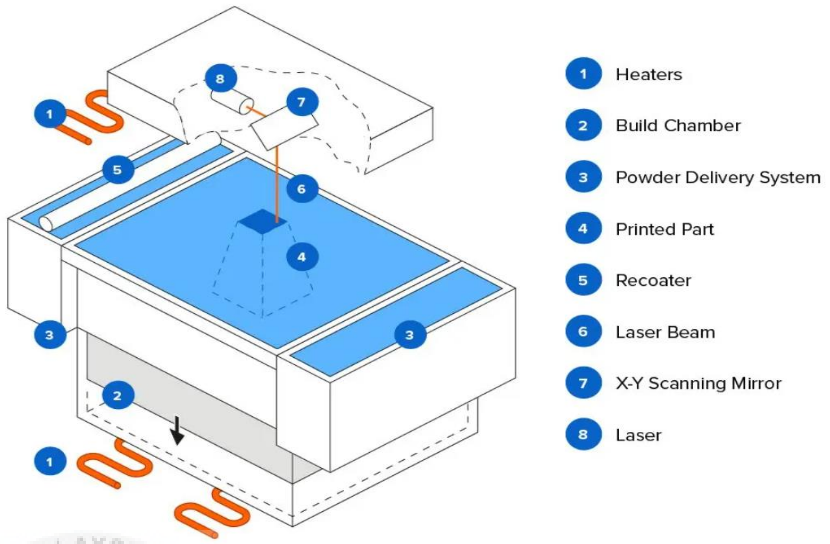

Figure 2. 2 Schematic of the selective laser sintering process (Guide, 2022)

2.3 General Overview 3D Scanner

A 3D scanner collects the form and looks of a real-world object or environment. The information gathered can subsequently be utilised to create three-dimensional computer models. During the latter half of the twentieth century, 3D laser scanning was created in an attempt to accurately reconstruct the surfaces of numerous things and places. In the realms of research and design, the technology is very useful. In the 1960s, the first 3D scanning technology was developed (Ebrahim, 2015). The objects are frequently scanned in 3D for a variety of reasons. To reconstruct a Reverse Engineering CAD Reference File or to quickly extract dimensions. The object itself is analyzed and documented via measurement. This is done in CAI, digital archive, and CAE analytics, among many other applications. Computer-assisted inspections are also used.

2.3.1. Process

Figure 2. 3 Model before and after applied 3D scanner (www.creaform3d.com)

There is the process that involves in the 3D scanner (figure 2.3):

1. **Data Acquisition Via 3D Laser Scanning.**

Hardware and software are both included in a data collecting and processing system. A hardware system captures point clouds or volumetric data by interacting with the surface or volume of an object of interest utilizing defined processes or phenomena. A computer programmer converts raw point clouds or volumetric data into a virtual representation of an object, such as surfaces and features. (Bia and Wang, 2010). From data acquisition through data processing, many different direct real-time interfaces may control the system all the way to data, making system integration into current operations simple. The laser probe is propelled above the object's surface by specialised software. Two sensor cameras continually capture the changing distance and shape of the laser line in three dimensions (XYZ) as it sweeps around the object as the laser probe sends a line of laser light onto the surface. (*Laser Design*, 2016).

2. **Resulting Data.**

The shape item displays on the computer monitor as millions of points termed a point cloud as the laser goes around capturing the whole surface shape of the object. The ergonomically designed T-Scan LV hand-held laser scanner reduces operator fatigue. It's light and balanced, making data collection possible even in difficult-to-reach locations. The T-Scan captures data at a rate of 210,000 points per second, making it one of the fastest scanners on the market. (*ZEISS Optotechnik T-Scan LV - Cam Logic, Inc.*, no date). The measurement volume of the system is $35m^3$.

3. **The Type of Modelling Chosen Is Determined by The Application.**

When cloud data files are created, it is recorded and fused in a 3D representation of the item utilizing a variety of application-friendly software packages.. (*Laser Design*, 2016)

4. **Inspection of Point Cloud Data.**

The scanned object can be compared with designer CAD nominal data if the data is to be used for inspection. This compare procedure comes in PDF format, which describes the difference between the screen and the CAD data pictorially, in the form of a 'colour map deviation report.' (*Laser Design*, 2016).

5. **CAD Model for Reverse Engineering.**

The quickest, precise, and automated technique to obtain 3D digital data for the reverse engineering is by laser scanning. The point cloud data is utilized to construct a 3D CAD representation of the geometry of a piece using specialist software. The CAD model enables the scanned object to be accurately replicated, or the object can be changed to rectify defects in the CAD pattern.(*Laser Design*, 2016). The process flow show in figure 2.4.

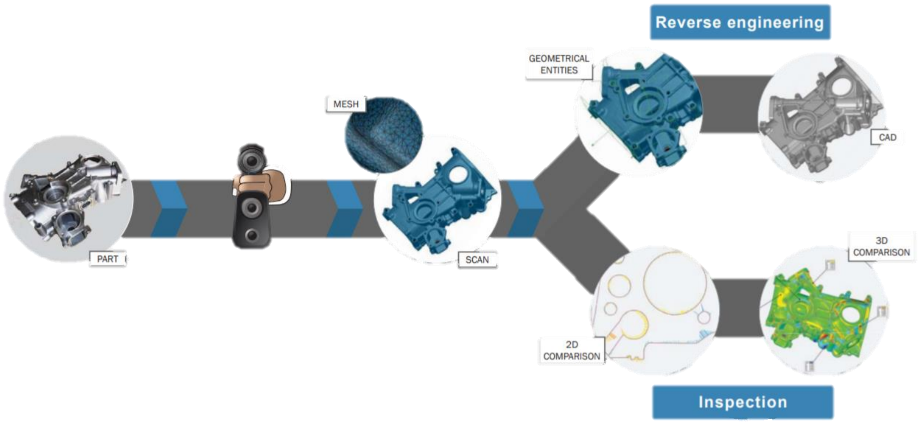

Figure 2. 4 Process 3D scanner (www.creaform3d.com)

2.3.2. Type of 3D scanner

3D scanner divides into two types are contact and non-contact. Non-contact solution also can be divided into two main categories, active and passive (Wikipedia Contributors, 2021). There are a few different types of 3D scanning method, and the principle-based on as follows:

1. **Laser-Based 3D Scanner**

Laser-based 3D scanners are shown in figure 2.5, the process called trigonometric triangulation. the method to accurately capture a 3D shape as a million od point. Laser scanner work by projecting a laser line or multiple lines onto an object and then capturing its reflection with a single sensor or multiple sensors (*Types of 3D Scanning Technologies and 3D Scanners*, 2020). A new laser scanner is constructed and built, and the scan measurement uncertainty and deviations are investigated and eliminated. The design includes the scanner's physical setup, point cloud extraction, and scanner calibration operations. It is designed to function in a spherical domain, allowing for a wide range of imaging views (Isa and Lazoglu, 2017). 3D laser scanner sensors are located at a known distance from the laser's sources. To calculate the reflection angle of the laser light the accurate point measurement is important. Laser scanners come in many designs and very popular. This laser scanner includes handheld portable units, arm based, CMM based, long-range, and single long-range trackers.

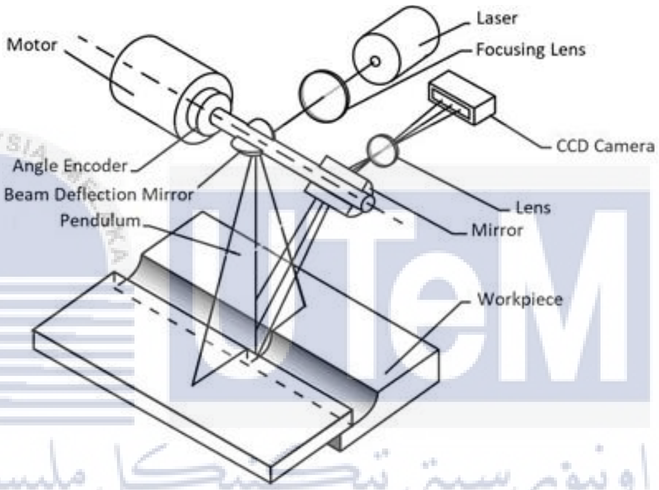

Figure 2. 5 Diagram of 3D laser scanner (www.linkedin.com).

2. Structured-light 3D Scanner

These scanners project a pattern of light onto a part and process how the pattern is distorted when light hits the objects (NeoMetrix Technologies, no date). The 3D scanner has one or more sensors that look at the edge of those patterns or structural shapes to determine object shape. The structure light 3D scanner is also known as "white light" 3D scanner and, mainly this model come with blue or white LED projected light. (*Types of 3D Scanning Technologies and 3D Scanners*, 2020). This model uses a same trigonometric triangulation method as laser scanner the distance from sensor to the light source is known. Figure 2.6 show the type of structure light 3D scanner.

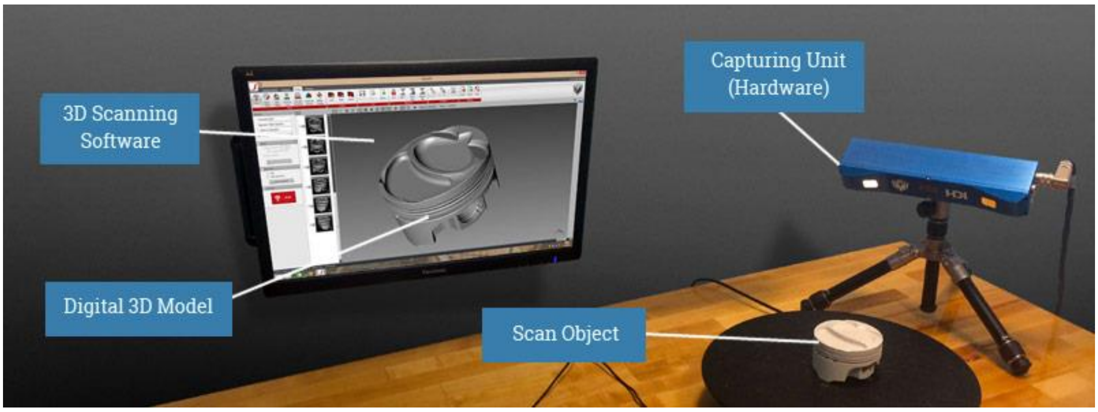

Figure 2. 6 Structured- light 3D scanner (www.linkedin.com)

3. Photogrammetry

Photogrammetry comprises all techniques concerned with making measurements of real-world objects and terrain features from images. These may be aerial as well as terrestrial images, and they may be taken by film cameras, digital cameras or electronic scanners on tripods, airborne or spaceborne platforms. Applications include the measuring of coordinates, quantification of distances, heights, areas and volumes, preparation of topographic maps, and generation of digital elevation models and orthophotographs (Aber, Marzolff and Ries, 2010). Photogrammetry is a subset of image processing that generates DTMs, DSMs, orthoimages, 2D and 3D object reconstruction and classification for mapping and theme applications, as well as visualisation. (maps, 3D views, animation and simulation) (Baltsavias, 1999). This approach involves taking a snapshot with a camera or using a smartphone with certain camera settings, then stitching the snapshot together using special software. To construct an accurate model, the user must input parameters such as the lens' focal length and distortion into the software. The high level of accuracy and speed with which data about an object is captured are two major advantages of using photogrammetry. Figure 2.7 show the type of 3D photogrammetry with Photo Scan.

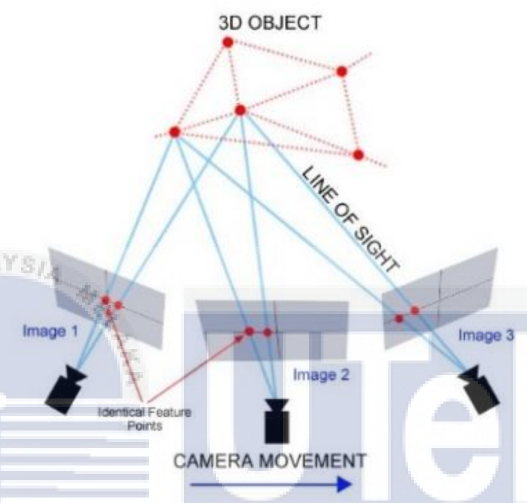

Figure 2. 7 3D photogrammetry with Photo Scan (www.linkedin.com)

2.3.4. Steinbichler Lv 3D Scan Component (Steinbichler LV 3D Scan)

The T-Scan LV/T-Track LV system is ideal for measuring big volume items in 3D. This all-in-one system, which includes a tracking camera, hand-held scanner, and optional touch probe, provides quick 3D data capture with exceptional precision and data range (*ZEISS Optotechnik T-Scan LV - Cam Logic, Inc.*, no date). This laser scanner is a complete solution, achieving a new dimension in coordinate measuring technology. The T-SCAN LV system consists of perfectly matched od following components:

a. T-TRACK LV Tracker

The T-TRACK LV tracker in figure 2.8 is an optical tracking unit with three internal cameras which allow detecting the infrared marker positions of the T-SCAN LV scanner or T-POINT LV touch probe and converting all to 3D coordinates as shown in figure 2.7. The optical tracking systems offer a high dynamic range for precise data capturing on different surfaces objects with varying surface properties (Zeiss.com.br, 2021)

Figure 2. 8 T-TRACK LV Tracker

b. T-SCAN LV SCANNER

The T-SCAN LV scanner is a line designed for digitizing object surfaces by using an optically amplified laser beam and a 2D camera. Based on the line acquired in this way, the positions of the individual points are calculated using triangulation as shown in figure 2.9 and 2.10

Figure 2. 9 T-SCAN LV Scanner

Figure 2. 10 T-SCAN LV Scanner Holder

c. T-CONTROL LV CONTROLLER

The T-CONTROL LV controller powers the sensor and it is responsible for collecting the required information and providing it to the connected computer as shown in figure 2.11.

Figure 2. 11 T-CONTROL LV

d. Connection cable

Connection cables are used to connect the T-TRACK LV Tracker, T-CONTROL LV CONTROLLER and computer to run the software.

e. Computer (e.g., laptop) including T-SCAN plus LV software

Computer are used for running the software which is PolyWorks software and save all the data from scanner.

2.3.5. Accuracy and Precision

When obtaining data measurements, accuracy and precision are two key aspects to consider. Precision indicates how repeatable measurements are, even if they are far from the recognised value, whereas accuracy indicates how close a measurement is to a known or accepted value. There are two definitions of "accuracy." In arithmetic, science, and engineering, accuracy refers to how close a measurement is to the true value. While precision is when measurements are repeated, precision refers to how consistent the results are. Random error, a type of observational mistake, causes precise values to deviate from one another. Figure 2.12 shows the difference between accuracy and precision and how can define the meaning of accurate and precise, not accurate and precise, accurate and not precise, and lastly not accurate and precise.

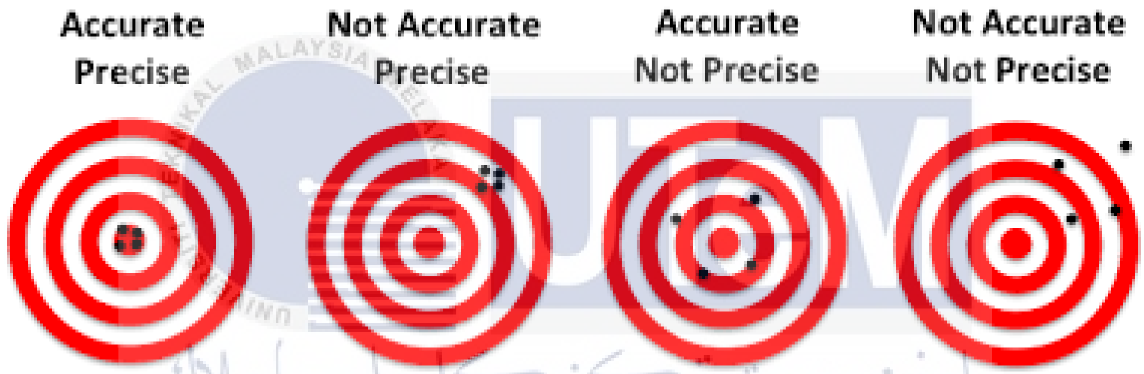

Figure 2. 12 Different accuracy and precision (danielmiessler.com)

Precision and accuracy must be assessed before employing any measuring or 3D scanning device. The calibration process is the most important step in building a precise 3D scanner. It is feasible to eliminate optical aberration difficulties and achieve precise and accurate three-dimensional data with proper calibration. In this work, a powerful calibration approach known as full-field calibration was used to get high-precision values utilising an original three-dimensional, calibrator that was designed to improve the performance of this sort of calibration (Galantucci, 2014)

A design's dimensional accuracy is influenced by a number of elements. When forward engineering is performed, the original design is given to production with a dimensional tolerance. This is done because no component can be manufactured without defects. Three sorts of mistakes are observed throughout the RE process: (1) manufacturing error linked to the tolerance specified in the initial design for manufacturing, (2) RE error related to the object measurements, i.e., the accuracy of 3D-scanning technology, and (3) new manufacturing error when RE design is applied for manufacturing (Helle and Lemu, 2021).

2.3.6. Application

The T-SCAN LV/T-TRACK LV system has a high measuring volume and is appropriate for all large volume measuring items (for example, car/automotive manufacture, line production, agricultural technology, welding construction/metal constructions, etc). Table 2.1 shown application for T-SCAN LV/T-TRACK LV and the function.

Table 2. 1 Application of 3D scanner system

Application	Function
Quality control / inspection	- CAD nominal vs. real comparison - Extraction of boundaries and edges (sheet metal parts)
Tool and mold making	- Tool reconstruction - Scan data for machining path generation - Actual capture after tool approval - Inspection of intricately welded structures setup of gauges and fixtures
Rapid manufacturing	- 3D data capture for rapid prototyping
Reverse engineering	- Reverse engineering data capture for very complicated geometries
Design	- Design model scanning for CAD downstream processing and documentation - Character line capture - Capture of base surfaces in a short period of time (alignment)
Archaeology, art-historical item recording, and so forth.	
Medical technology applications (motion analysis, etc.)	

2.3.7. Technical Data For 3D Scanner

These figure 2.13 show the technical data for ZEISS T-TRACK optical tracking system.

	T-TRACK CS+	T-TRACK 20	T-TRACK LV
Measuring distance: object-camera	2.0 m – 4.0 m	2.0 m - 6.0 m	1.5 m – 7.5 m
Measuring volume	6.3 m^3	20 m^3	35 m^3
Field of view	Up to 2466 mm x 2178 mm	Up to 3200 mm x 2500 mm	Up to 3700 mm x 2600 mm
Measuring rate	Up to 4 kHz	Up to 4 kHz	Up to 4.5 kHz
Weight	18.5 kg	18.5 kg	24 kg
Dimensions	1150 x 180 x 150 mm	1150 x 180 x 150 mm	1157 x 230 x 175 mm
PC	Notebook or desktop PC	Notebook or desktop PC	Notebook or desktop PC
Available software	ZEISS colin3D Direct real-time interfaces available with almost all standard software packages	ZEISS colin3D Direct real-time interfaces available with almost all standard software packages	ZEISS colin3D Direct real-time interfaces available with almost all standard software packages
Possible configurations	T-SCAN CS/T-POINT CS/T-REF CS	T-SCAN 20 / T-POINT 20 / T-REF 20	T-SCAN LV/T-POINT LV/T-REF LV
Accuracy traceable to DIN EN ISO 10360	–	Yes	–

Figure 2. 13 Technical Data (www.metalia.es)

2.4 Reverse Engineering Applied

The coordinate measurement machine (CMM) and CAD/CAM software are used to create the RE application environment (Zhang, 2003). Reverse engineering technology can be used to improve and innovate existing product models as an advanced production technology. Three dimension scanning equipment may also be used to collect information on the surface of an object, which is reconstructed with the help of reverse modelling software and the 3-D model computer so that the product can be processed back again. (Wang, 2021). The use of 3D scanning in reverse engineering processes, as shown in figure 2.14, requires three primary stages: (1) scanning, (2) point processing and (3) geometrical model development relevant to applications. The stages indicated in the graphic demonstrate the phases in which the engineer changes the object into a CAD model from physical to point cloud (Helle and Lemu, 2021).

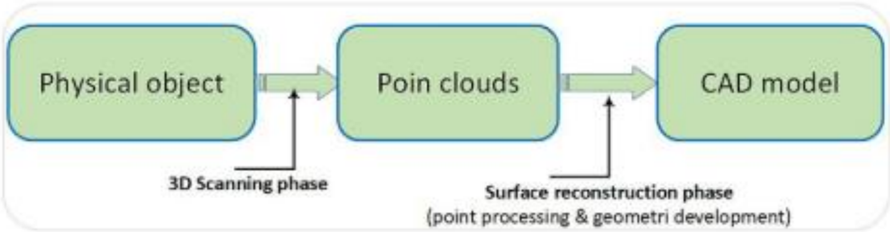

Figure 2. 14 Different accuracy and precision (danielmiessler.com)

2.4.1. Point Cloud Data Collection and Process

Real-world point cloud objects pose great challenges in point cloud classification as objects acquired by scanning devices from real-world scans are often cluttered with background and are partial due to occlusions as well as reconstruction errors . Cloud Point Data is a collection of space data points. The data points are collected by the coordinate system. The points are a 3D shape or object, with each point having its co-ordinate X, Y and Z. 3D point cloud segmentation is known as 3D point cloud segmentation in various homogeneous areas. Points will have identical properties in the same region. Due to the considerable duplication, irregular sample density and absence of explicit cloud data organisation, segmentation is problematic. (Nguyen and Le, 2013). As the output of 3D scanning processes, point clouds are used for many purposes, including to create 3D CAD models for manufactured parts, for metrology and quality inspection, and for a multitude of visualization, animation, rendering, and mass customization applications (*tech27.com resources*, 2018)

2.4.2. Data Segmentation

A physical object is digitally recreated from a set of boundary points in reverse engineering. These points are organised into subgroups during the segmentation phase to make subsequent procedures such as surface fitting easier (Vančo and Brunnett, 2002). Data Segmentation is the process of taking the data that hold and dividing it up and grouping similar data together based on the chosen parameters so that it more efficiently within marketing and operations. According to the original features of the physical object, the data is divided into different areas and each one can be fitted with a curved surface (Kim, Hur and Lee, 2002). Then, the methods of transition and intersection between the surfaces are adopted to reconstruct the them, meaning they can later be connected within a complete surface shape (Wang, 2021).

2.4.3. Surface Reconstruction and Sample Modelling

Earlier works of surface reconstruction focused on reconstructing piece-wise smooth surfaces, while recent works have focused on addressing the significantly challenging data imperfections. The properties of the point cloud effect the behaviour of the reconstruction algorithms. Reverse Engineering (RE) surface reconstruction and modelling techniques highlight the need to develop new methods and computer-based tools to simplify the process and improve the quality of the finished output, despite the huge number of potential fields of application. In developing free-form form design items, the criterion is particularly significant (*(PDF) Surface Reconstruction Method for Reverse Engineering Based on Aesthetic Knowledge*, 2006). During the initial step, the designer sketches and sculpts wood or clay models to demonstrate concepts. Following this creative phase, the process is defined by multiple iterative design evaluations carried out directly on the physical mock-up, which must then be turned into a 3D virtual model for product engineering activities. The transformation of raw point cloud data into CAD-usable information is a critical step in surface reconstruction The transformation of raw point cloud data into CAD-usable information is a critical step in surface reconstruction. According to, there are three primary approaches that are often utilised, as shown in figure 2.15 wire-frame modelling, surface modelling, and solid modelling. This subchapter will concentrate on the first two because they are the most commonly used. The most basic form is wire-frame modelling, which stores data as a collection of points, lines, and various sorts of curves. Although wire-frame modelling has the advantage of requiring less data storage, it cannot meet the needs for current sophisticated designs with free-form surfaces.

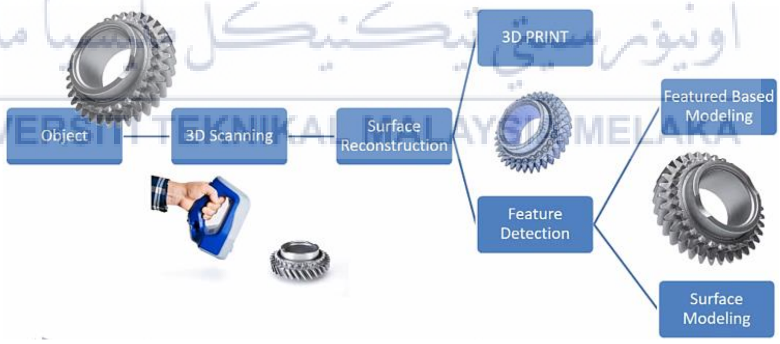

Figure 2. 15 Surface reconstruction process (www.creaform3d.com)

a) Polygon mesh models: In a polygonal depiction of a form, a curved surface is represented by multiple tiny faceted flat surfaces (think of a sphere modelled as a disco ball). Polygon models, also known as Mesh models, are helpful for visualization and certain CAM (i.e., machining), although they are "heavy" and uneditable in this form. The reconstruction to polygonal model method includes locating and linking adjacent points with straight lines to create a continuous surface. For this reason, there are various apps accessible (e.g., MeshLab, Point Cloud for AutoCAD, JRC 3D Reconstruct or, image model, PolyWorks, Rapid form, Geomagic, Image ware, Rhino etc., both free and paid.)

b) Surface models: the next level of modelling sophistication is to represent our item as a patchwork of curved surface patches. NURBS, T Splines, and other curved topological representations might be utilized. Because of NURBS, our sphere is a true mathematical sphere (Non-Uniform Rational B-Splines). Some programs support manual patch layout, however the best-in-class support both automated and manual patch layout. When converted to CAD, these patches have the advantage of being lighter and more manipulable. Surface models are modifiable, but solely in the sense of pressing and pulling to deform the surface in a sculptural sense.

c) Solid CAD models: the editable, parametric CAD model is the ultimate representation of a digital shape from an engineering/manufacturing standpoint. After all, CAD is the industry's standard "language" for describing, editing, and maintaining the shape of a company's assets. Our sphere is described in CAD by parametric features, which may be simply changed by altering a value (e.g., center point and radius)

There are few examples of modelling are used, including simple shape, geometrical shape, and complex shape.

a) Simple Shape

Simple shapes are basic geometric objects such as a point, a line, a curve, a plane, a plane figure (e.g., square or circle), or a solid figure (e.g., cube or sphere). The bulk of natural forms, on the other hand, are complex. Figure 2.16 shown the simple shape.

Figure 2. 16 Simple shape (en.wikipedia.org)

b) Geometry Shape

Geometric Shapes are described as a figure or area enclosed by a boundary made up of a specified number of curves, points, and lines. Triangle, Circle, Square, and other geometric shapes are examples (*Geometric Shapes: List, Definition, Types of Geometric Shapes*, 2017). Figure 2.17 shown geometry shape sample.

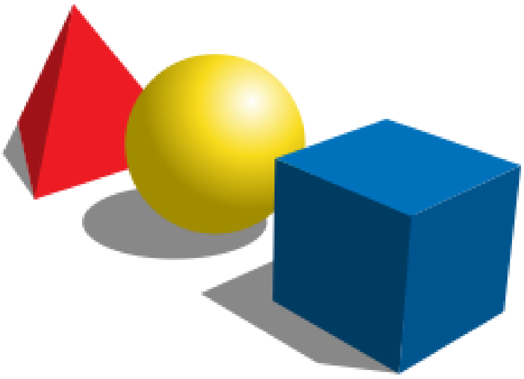

Figure 2. 17 Geometry shape (en.wikipedia.org)

c) Complex Shape

Complex forms combine the simplicity of some or all. These complicated forms are polygons and other forms with components of circles, squares, triangles, ellipses, and rectangles.

2.5 Software Construction

2.5.1. CAD

Architects, engineers, and construction professionals use AutoCAD computer-aided design (CAD) software to generate exact 2D and 3D designs. (*AutoCAD Software, 2022*). CAD software is used to improve the designer's efficiency, the quality of the design, communication through documentation, and the creation of a database for production. (*Computer Aided Design and Manufacturing - M.M.M. SARCAR, K. MALLIKARJUNA RAO, K. LALIT NARAYAN - Google Books*, 2008). For product design and production operations of the programmes, such as CNC machining, the CAD/CAM software is employed. CAM software generates tool channels which drive machine tools to turn designs into real components using CAD software models and assemblies, such as Fusion 360. The design and manufacture of prototypes and completed items is all made with the help of CAD/CAM software

2.5.2. CATIA V5

CATIA stand for Computer Aided Three-Dimensional Interactive Application. CATIA V5 is the software covering most of today's common field, including the design of the product life cycle, analysis, simulation and optimisation, drawing and NC programmes for production itself. This encompasses the design from initial to product building (Naprstkova, 2011). CATIA V5 can be utilised file-based or in conjunction with another software package that includes PLM, such as ENOVIA or SMARTEAM.(*TECHNIA*, 2020). It may be utilised and executed in a wide range of sectors, such as car or aviation, consumer products, machinery tools, and heavy engineering capital equipment. All CATIA V5 are based on three platforms: P1, P2 and P3. The data generated in one platform can be utilised on one product from another platform, focused on particular levels, according to client demands. (Naprstkova, 2011).

Table 2. 2 Function of Catia Software

Application	Function
Part Modelling	Part Design workbench
Assembly Modelling	Assembly Design workbench
Surface Modelling	Generative Surface Design workbench
Finite Element Analysis	Generative Structural Analysis
Sheetmetal Part Design	Generative Sheetmetal Design
Rendering	Real Time Rendering workbench

2.5.3. PolyWorks

PolyWorks is the most widely used reverse engineering and inspection software on the market today. PolyWorks' process has sub-processes, as indicated in the workflow below:

1. Acquiring Data

PolyWorks may be used to find point clouds or to scan a document with the help of a digitizer and PolyWorks plug-ins. Then, if the point clouds have previously been aligned, assess the alignment quality before moving on to reverse engineering or inspection.

2. **Reverse Engineering**

The aligned point clouds build a high-quality polygonal model, modify the polygonal model to meet the demands of your downstream application, and even generate high-quality NURBS surfaces.

3. **Inspection**

Compare the aligned point clouds to a reference object using user-defined tolerances. Take accurate measurement and create the customized report to find the data. The simple operation of workflow for PolyWorks is shown in Figure 2.18.

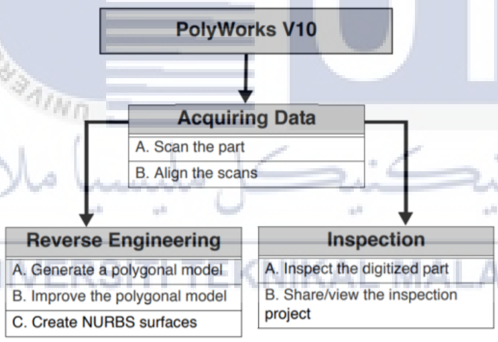

Figure 2. 18 Workflow for PolyWorks (kb.unavco.org)

2.6 Comparison of Dimensional and Time Method of Product

2.6.1. Morphology Surface

In construction, 2D and 3D techniques are used to study the morphology of concrete surfaces. Non-destructive 3D optical techniques, which allow for the creation of a three-dimensional virtual image of the examined surface without causing damage to the researched element's structure, are currently under development (Czarnecki, Hoła and Sadowski, 2014). By analysing this image with special computer software, data for the 3D roughness characteristics specified in standard can be generated, which are required for determining the pull-off adhesion of concrete layers in layered constructions such as floors.

- **3D techniques of investigating morphology of concrete surfaces.**

Light refraction on the examined surface is used by laser scanning techniques (Budzik, Gessner and Wieczorowski, 2010). Parallel fringes are created by a laser scanner (bands). The deviations of the fringes from their predicted placement on a perfectly flat surface are used to quantify differences in elevation between places on the studied surface (Czarnecki, Hoła and Sadowski, 2014). The laser scanner has two cameras that record light fringes that form a cloud of points and assign three coordinates to each measurement point with a 20-meter precision. The refraction of light fringes is measured independently by the two cameras, and if substantial changes are observed in one of the measuring points, the measurement is repeated. The laser scanner can examine quite large surface areas (2000 mm x 1600 mm). If bigger regions are to be scanned, the scanner must be calibrated (which takes time) so that the gathered data may be combined. 3D technique based on light refraction Figure 2.19 shown schematic of test setup and figure 2.20 example of concrete surface roughness investigation.

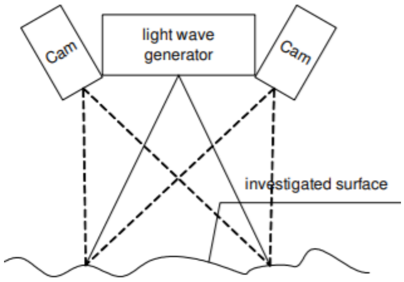

Figure 2. 19 Schematic of test setup (Czarnecki, Hoła and Sadowski, 2014)

Figure 2. 20 Schematic of test setup (Czarnecki, Hoła and Sadowski, 2014)

2.6.2. Calibration

Calibration is the recorded comparison of the measuring instrument to be calibrated against a traceable reference device (*www.Beamex.com*,2021). A device that creates the quantity to be measured, such as a voltage or a sound tone, or a physical artefact, such as a metre ruler, might also be employed as a standard. Instrumentation design revolves towards removing or eliminating factors that lead to faulty measurements. In calibration the correlation at specific locations within the operating range of the instrument can be determined by a few calibrators. When several calibrators are used to establish the relation of calibration or "curve" a big number of calibrators might overweight the time and labour required in the creation and testing of their performance. The instrument performs optimally when the intermediate points specified in the manufacturer's performance requirements are utilised for calibration; the recommended procedure effectively removes, or "zeroes out," the inherent instrument error at these sites (*Advanced instruments*, 2018).

- **Accurate calibration method for a 3-D laser scanner**

A laser emitter and a camera with fixed relative positions make up the acquisition system. A cylindrical lens is also included with the laser housing, allowing it to project a plane light. To separate the laser stripe from the rest of the scene, an optical filter was also used. A digital micrometre was used to calibrate the system, which moved a target with known dimensions. The calibration method is based on the geometrical link between the laser stripe's 3-D coordinates on the target and its digital coordinates in the image plane being modelled (Niola *et al.*, 2011).

CHAPTER 3

METHODOLOGY

In this chapter, brief information of process of 3D scanning method will be presented. The flow of the methodology is shown in figure 3.1.

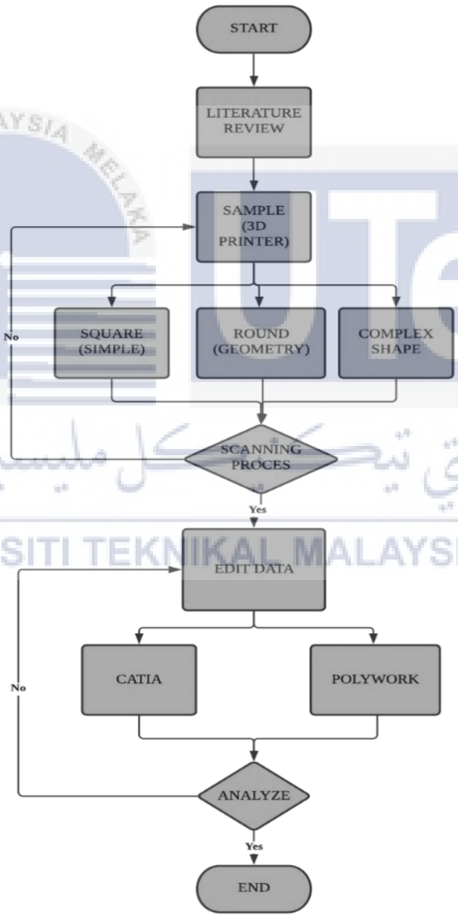

Figure 3. 1 Flowchart of methodology process

The procedure of comparison the best method software and the time taken also will be presented after the process of 3D scanner.

3.1 Sample Preparation

This sample preparation to study focuses on selective laser sintering, with the Farsoon 402P SLS 3D Printer serving as the SLS 3D printing mechanism. This printer is available in the faculty lab. The printing process has three phases that need to be followed to avoid errors and faults in parts and components. The process involved is Pre-process, Printing process and Post process.

3.1.1. Pre-process

The pre-preparation process is divided into many steps that must be accomplished. This method must be performed in order to prevent system errors. The process's pre-build preparation is shown in figure 3.2 below.

1. Import Car STL file form CAD software and open STL file on farsoon buildstar software in SLS Farsoon 402P Machine.
2. Arrange Car model STL data on 3 posotion XY Direction, YZ Direction and ZX direction
3. Select verify icon and test collision on BULIDSTAR software
4. Slicer all part and that software show require high powder require to print this model.
5. Press estimates time and that time require to print will show in screen
6. Press estimates powder and that powder high in chamber require to print will show in screen
7. Save all data and close BUILDSTAR software.

8. Based on size chamber and density of powder polyamide 12 calculate volume powder in KG.
9. Based powder calculate divided on powder ratio require by machine : 40% Virgin, 40 % Recycle and 20% Reheat material
10. Mixing all powder using mixer machine.

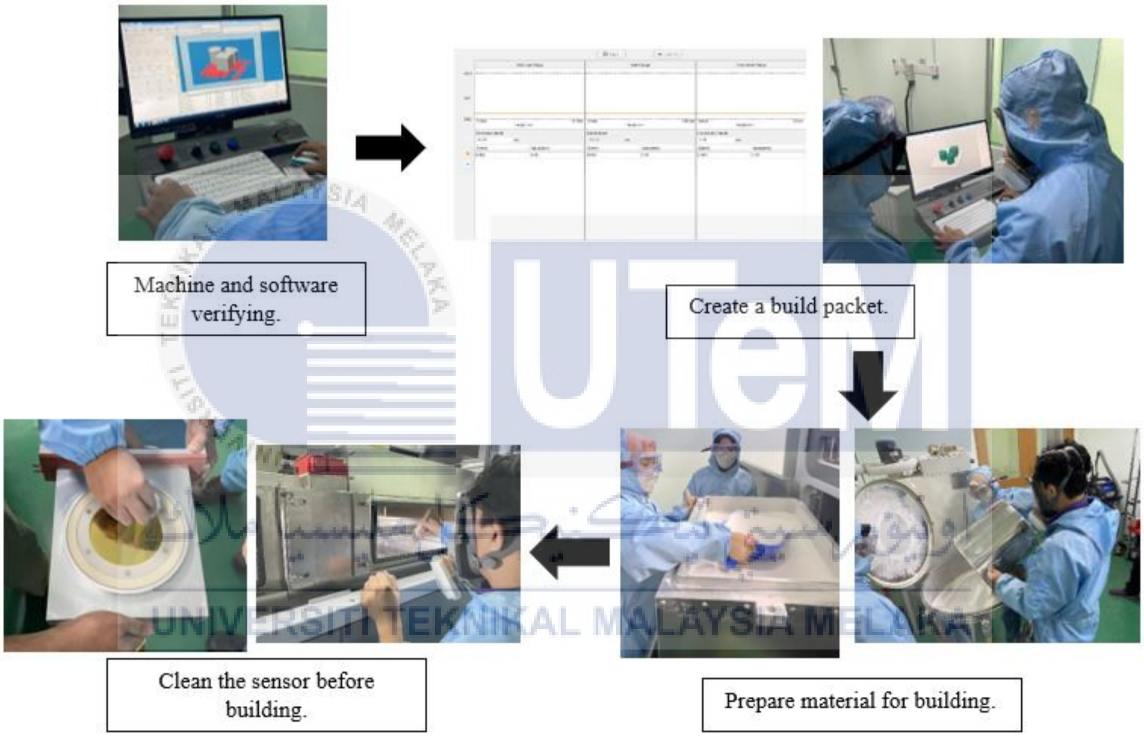

Figure 3. 2 Pre-process 3D Printer

3.1.2. Printing process

This procedure may be divided into multiple parts, each of which focuses on software setup on the machine's computer, as well as operating the machine chamber to remove or add material powder and positioning the 3D model during the printing process. The printing process show in figure 3.3 below:

1. A designer creates a 3D model in order of a Computer-Aided Design (CAD) application.
2. The design has been divided into thin (2D) layers.
3. The SLS printer receives the divided design.
4. A levelling roller distributes a small coating of powdered material on the build platform of the printer.
5. A CO2 laser heats and fuses the material as it traces a cross-section of it.
6. When a layer is finished, the construction platform is lowered to make room for the following layer of powder.
7. After each layer is completed, any unused material is recycled.
8. The SLS process is repeated, layer by layer, until the component is finished.

SLS pieces are encased in unsintered powder throughout the printing process. This additional powder acts as a support structure for the component during printing, eliminating the requirement for support structures.

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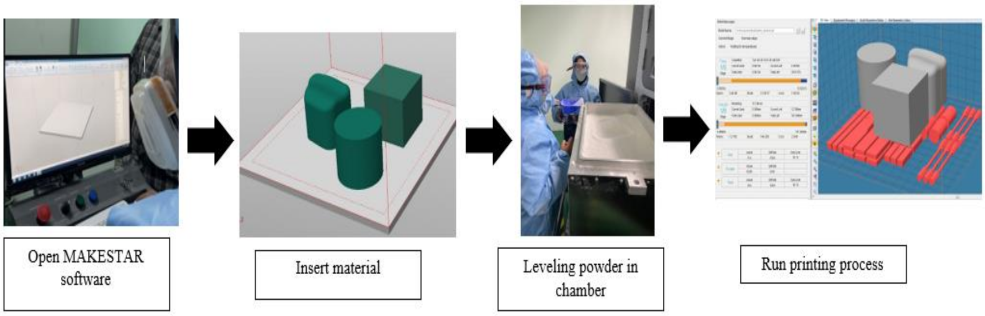


Figure 3. 3 Printing process 3D Printer

3.1.3. Post-process

In this process are the last process in 3D printing. The post-process shows in figure 3.4 below. Part recovery is the first step in SLS post-processing. Parts that have recently been SLS printed are contained in a porous cocoon of partially sintered powder that must be torn apart in order to extract the part. While this technique would be filthy in a domestic setting, SLS is mostly employed in industrial settings, where specially constructed cleaning chambers with airtight enclosures and compressed air inlets are used. SLS-printed items are reviewed and tested after they have been cleaned to verify, they fulfil the original requirements. Because SLS components are susceptible to shrinkage and warping, this method must guarantee that each part is appropriate for purpose (Team, 2021).

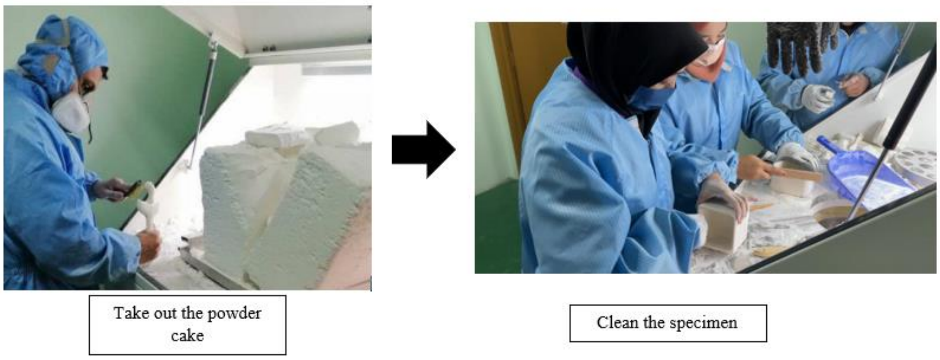


Figure 3. 4 post-process 3D Printer

3.2 Sample Product

In this sample product will explain about sample are printed using Selective Laser Sintering (SLS) 3D Printer. This sample are divided into 3 type of sample shape which is square shape, cylinder shape, and complex shape sample. The specification about the type of sample is:

3.2.1. Square Shape

This square shape is the simple shape because this sample shape just has simple basic geometry and not complicated to design. In figure 3.5 show the simple shape sample. The sample square shape is printed by Selective Laser Sintering (SLS) 3D Printer. The size of this product is 100 mm x 100 mm. Material of this product is nylon. This product no need to coating before 3D scanner because a surface permits the greatest detection of light and resulting in an excellent, quality 3D image.

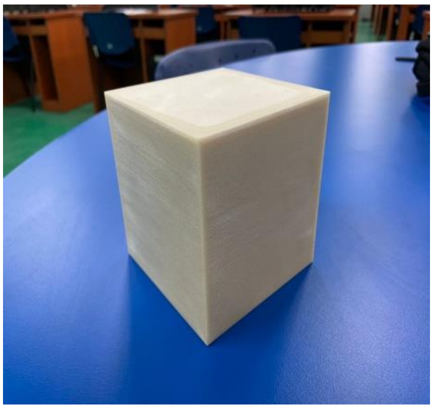


Figure 3. 5 Sample Square Shape

3.2.2 Cylinder Shape

This cylinder shape can classify as geometric shapes because as a figure or area closed by a line formed by mixing precise quantities of curves, points, and lines. The example product of geometric shape sample shown in figure 3.6. The sample cylinder shape is printed by Selective Laser Sintering (SLS) 3D Printer. Material of this sample product is nylon. This sample product no need to coating before 3D scanner process because this product no in category clear material, pitch-black objects, or shiny metal parts.

Figure 3. 6 Sample Cylinder Shape

3.2.3 Complex Shape

Complex shapes are the design has the combination a few or all the simple shapes. Figure 3.7 showed that this project will have the complicated shape of a 3D scan. These complicated shapes are polygons and other forms with components of circles, squares, curve, and edge. The sample complex shape is printed by Selective Laser Sintering (SLS) 3D

Printer. Material of this sample product is nylon. This sample product no need to coating before 3D scanner process because this product no in category clear material, pitch-black objects, or shiny metal parts.

Figure 3. 7 Sample Complex shape

3.3 Scanning Process

The scanning process for will be use 3D scanner (T-scan LV system) brand. The method 3D scanner for T-scan LV system is:

3.3.1 Method Scanning

Setup all the component of T-Scan LV 3D scanner from the casing or the boxes. Arrange the suitable position for all the component at the suitable place that can do the 3D scan easily. After settle setup all the component, connect all the cable as shown in figure 3.8 and T-Control LV Controller switched ON. After that, T-Track LV Tracker and laptop with POLYWORK license also switch ON and run the POLYWORK software. The T-Scan LV scanner always place on the T-Scan LV Scanner Holder whenever use it.

Figure 3. 8 Setup all component

The sample product was setup in front of T-Track LV Tracker and make sure scanning part can cover the range of the T-Track LV Tracker Lens. Therefore, the estimation distance of between sample product and T-Track LV Tracker must be below 3.5m and it must the best coverage of the whole sample product to scan as shown in figure 3.9. The time taken for setup around 30 minutes.

Figure 3. 9 Distance whole sample product to scan

The sample product should be clean from the dust and dirt. This is caution must take for avoid texture form on the surface during scanning and it also avoid affecting the result of analysis.

The T-Scan LV Scanner used for scan sample product surface with correct position. This process is the easy and critical that our hand should be flexibles and hand not shake or vibrate during scanning the sample. The scanning should be in one direction and cannot be multi-direction way to scan. During scanning, the sample product cannot move direction or angle and the person or object cannot block the view sensor between T-Track LV Tracker and T-Scan LV Scanner. The most suitable scanning place should be at room temperature. All this safety procedure must follow to get a smooth surface with the perfect accuracy and precision surface.

3.4 Editing Cloud Data

Editing cloud data is the process of setting and combining the actual part and scan part by using PolyWorks and CATIA software. This chapter will go over all of the steps required in modifying cloud data, from the beginning to the end.

1. **Basic PolyWorks/workspace manager (figure 3.10).**

a. To activate it and access its content, click a Workspace name in the Workspaces section

b. Click on an item in the current object workspace tree and look at its attributes, next steps and notes in the Wizard window.

c. By right-clicking over an object, you can open a shortcut menu for that object.

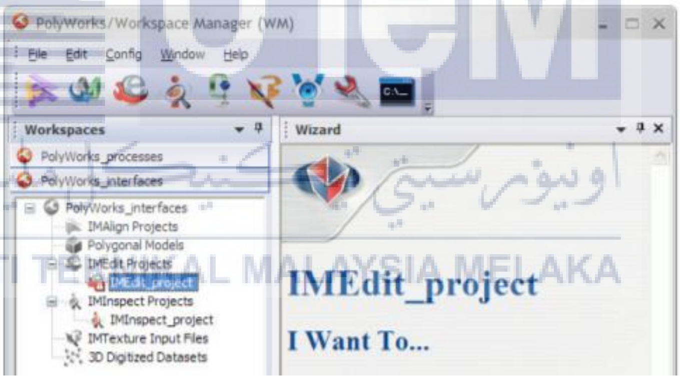


Figure 3. 10 workspace manager PolyWorks (kb.unavco.org)

2. **Interface Basics**

The active workspace has two projects: an IMEdit Project and an IMInspect Project. Before beginning the process, create an IMEdit or an IMInspect project.

a. IMEdit: In the current workspace's IMEdit Projects branch, pick IMEdit project and click "Open the IMEdit project" in the Wizard box. The IMEdit module is launched.

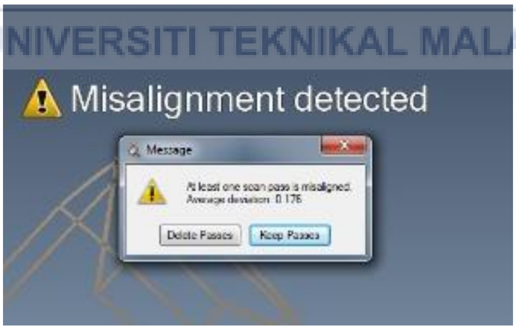
b. IMInspect: In the active workspace object tree's IMInspect Projects branch, pick IMInspect project and click "Open the IMInspect project" in the Wizard window. The IMInspect module is launched.

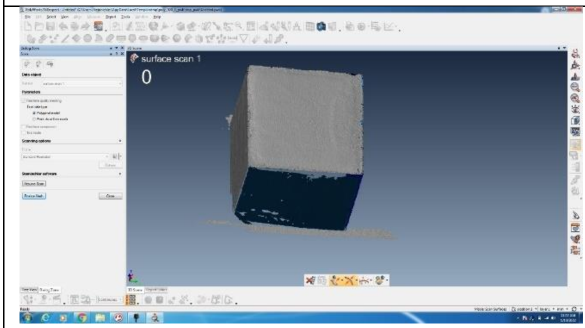
3. IMInspect process.

Before getting the cloud data, Table 3.1 describes the processes in the IMInspect technique for scanning data samples with a T-Scan LV scanner.

Table 3. 1 IMInspect process (kb.unavco.org)

Process	Description/ process
	Click on the start IMInspect
	Click on the the steinbicher T-scan/ Optotrack at the arrow beside of scanning device and Click on the connect to steinbicher T-scan/ Optotrack at the main icon of probing device.

	Click on the Scan to steinbicher T-scan/ Optotrack at the main icon of scanning device
	Set the data type to polygonal mode and click the start. Then can start scan the sample product (simple shape, geometry shape and Complex shape) and it will display the scan part in Polywork software.
	If misalignment detected on the screen, select the delete passes option. • Tracker movement or vibration, temperature effect, or multi-direction scanning are all things that the tracker cannot detect.

	After finish scan, click End Scan > Finalize Mesh. After the data Finalizing, click close.
	Finally, will get scan part of the sample shape product (Square shape, Cylinder shape and Complex shape)

4. Save The Results.

Open a working area for PolyWorks The workspace manager should be open and the workspace PolyWorks_processes.pwk in the workspace area should be open.

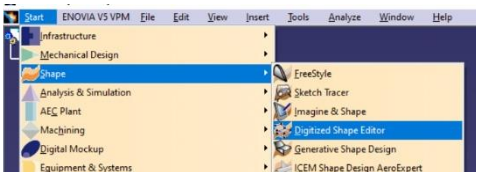
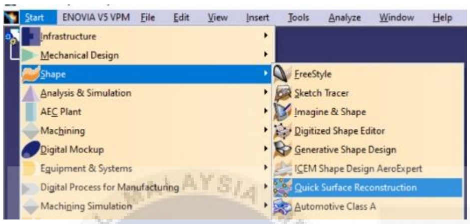
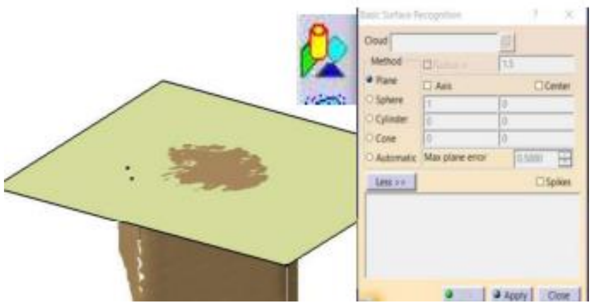
a. To active the workspace, click IMInspect_Project_for_IMView .

b. Click "View Project IMInspect" on the Wizard window.

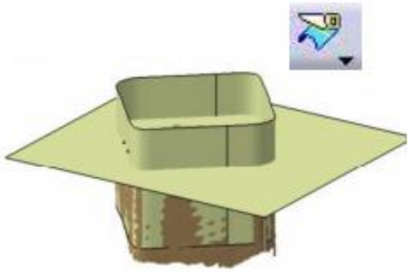
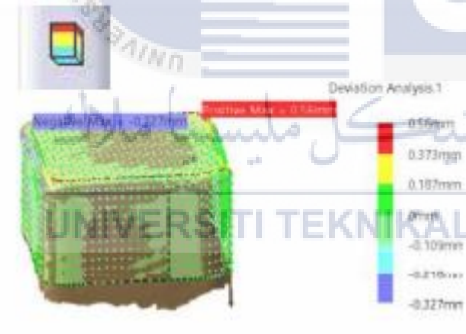
5. Imedit Process.

The IMEdit data process will be split into two software programmes, Catia and PolyWorks, to locate cloud data from a sample that was scanned with a T-Scan LV scanner and saved as. stl file. Table 3.2 and table 3.3 will show IMEdit data process using Catia software and other one PolyWorks.

Table 3. 2 IMEdit process Catia Software

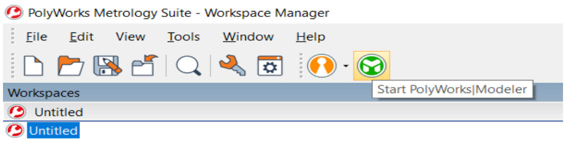
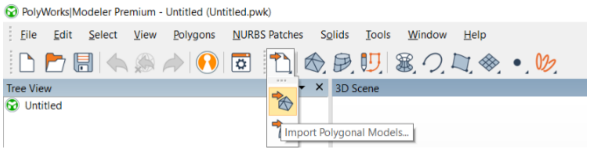
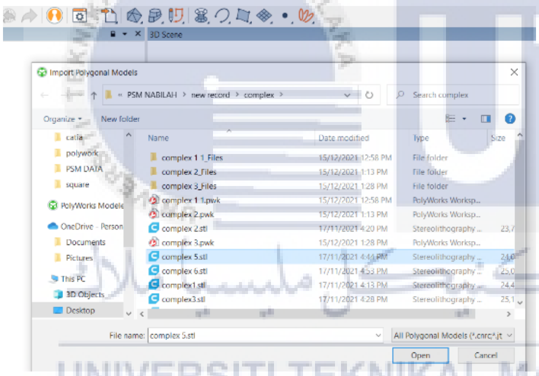
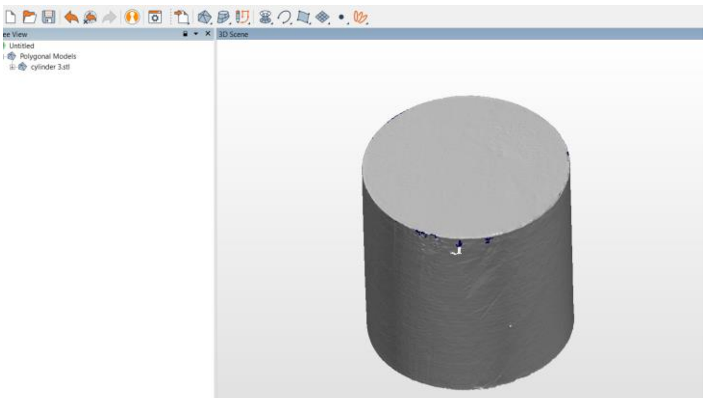
Process	Description/ process
	Shape > digitized shape editor for import scan result that save as .stl format.
	Change from digitized shape editor to quick surface reconstruction
	Insert cloud data select icon activate and choice flat area
	Select icon basic surface recognition for crate plane

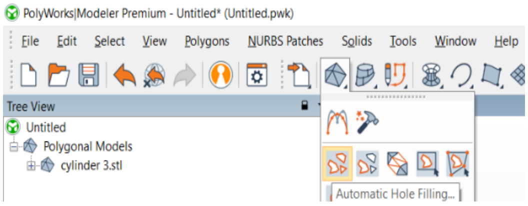
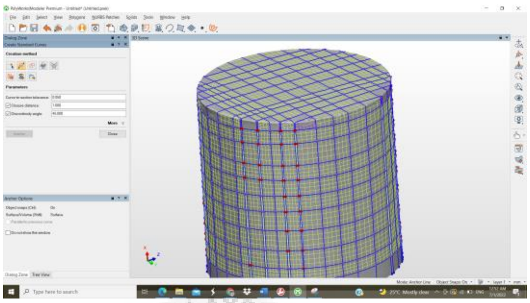
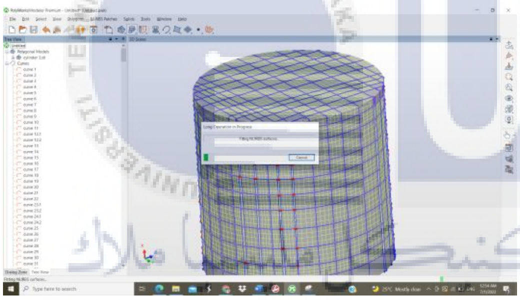
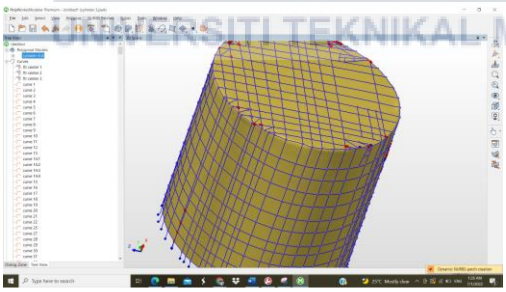
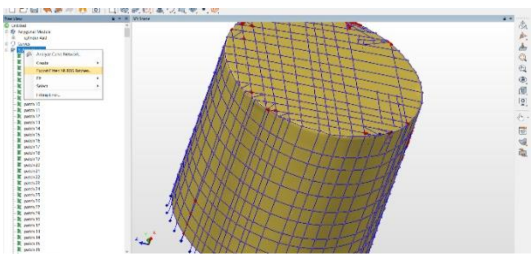
	Select icon split and remove all surface outside cloud data region
	Select icon curve from scan for convert cloud section to line section
	Select icon extruded and extrude line section

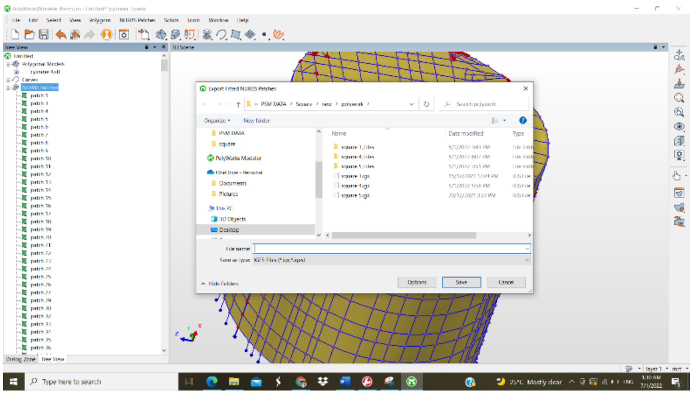
	Select icon split and remove all surface outside cloud data region
	Join all surface and apply fillet at edge
	Analysis data between cloud data & surface create

The IMEdit procedure utilising Catia software is shown in table 3.3. Catia software may be used to alter data in a variety of ways, including employing plane, section, and circle types. Editing Cloud Data Using Section Method is explained in Table 3.3.

Table 3. 3 IMEdit process PolyWorks software (kb.unavco.org)

Process	Description/ process
	Open Polyworks software and select start Polywork|Modeler
	After that, click file and import Polygonal Model
	Then choose the actual part that (name file.stp) file and then click open.
	Click on the Center on All Objects. It will view the actual part and scan part in one window.

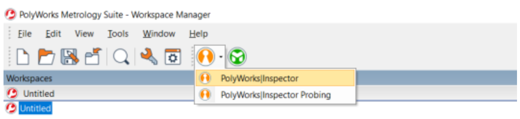
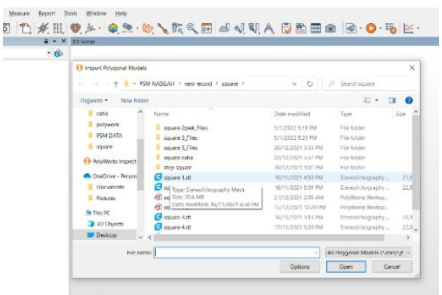
	Click polygonal and choose automatic Hole Filing for fill all the hole in scan part and click start.
	Next, click on curve and choose create standard curve and click anchor line to create point line.
 	Next, click on NURBS patch and choose fit-all NURBS patch. Complete the hole with line. Click active Dynamic NURBS patch creation.
	Click on curve at the tree and choose NURBS patches, right click and click on export fitted NURBS patch to save the work.

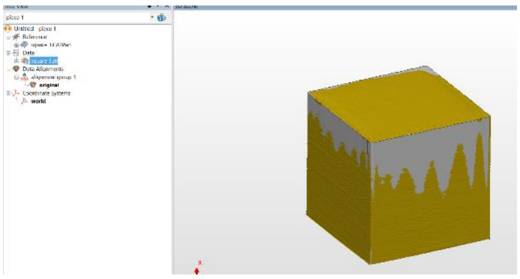
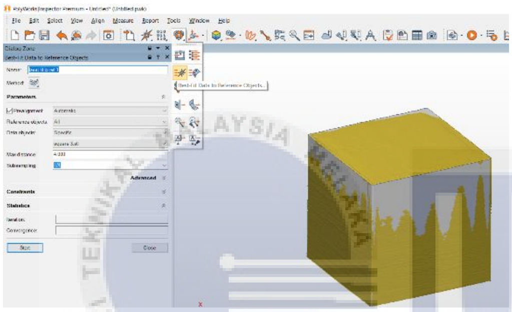
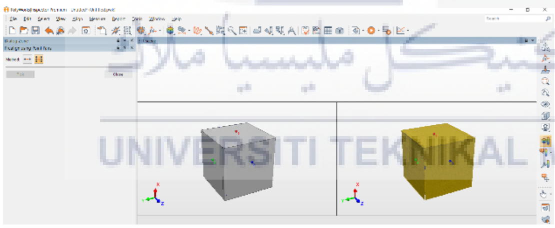
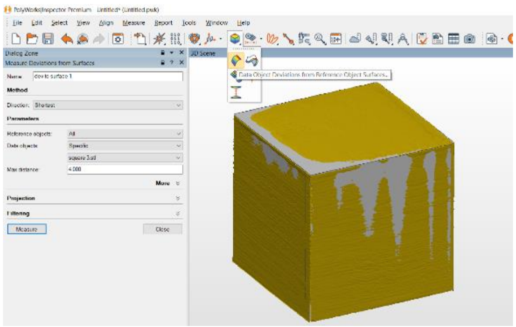
	Save the file as .igs file

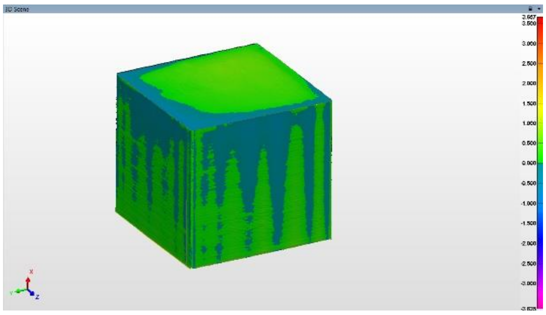
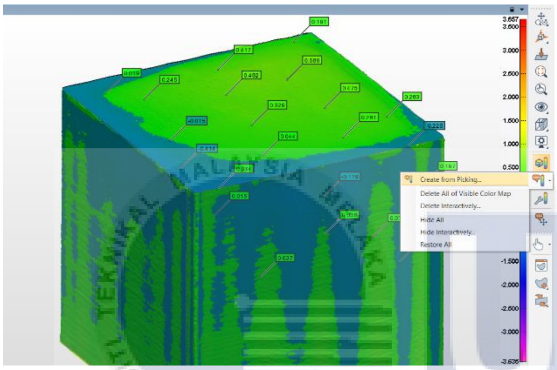
3.5 Analysis Data

There are a few procedures to perform in PolyWorks Software when analysing data. At this point, the PolyWorks will finish processing the analysis results. The final stage is to obtain analysis data, which may be seen in tables 3.4 for PolyWorks, respectively.

Table 3. 4 Analysis data Polyworks software

Process	Description/ process
	Open PolyWorks software and click PolyWork|Inspector.
	Click import polygonal and import CAD model.

	
	Click Best-fit Data to Reference Object. Setting realignment, reference object and data object. Click start.
	Click point by using Realign using Point Pairs.
	Click on the Data Object deviations from Reference Object Surface

	Click Measure and then will get the colours on the surface part which indicate the tolerance between two parts
	Click on the surface colours parts to display the tolerance gap value. Finally come out with an analysis data

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will go through the outcomes of each 3D scanner's editing cloud data analysis. Based on chapter 3, there were three types of samples which is square, cylinder and complex shape will be analyse the analysis of methods for after editing cloud data using PolyWorks and Catia. This chapter will also show the difference in editing cloud data duration time comparing actual CAD data and scanning CAD data. The overall total surface out of tolerance can be determined by a few characteristics.

Within this chapter, Deviation Analysis will discuss for cloud data that get from the three times for CATIA and PolyWorks software (Mah, Samson and McKinnon, 2011). Deviation analysis will determine how accurate design software are before determining which is the best approach software for obtaining cloud data using a 3D scanner. At the same time, the best time will be to note for the result deviation analysis that which software better will used.

Create a table of the time taken editing cloud data on each way phase editing using PolyWorks and Catia based on the analysis (Hawryluk and Ziemba, 2018). Draw a graph from the table based on the time taken on scan activities and a graph based on the time spent editing cloud data. Finally, each method phase process was explained. This chapter will also include an overall editing cloud data analysis graph and a discussion of the overall finishing process analysis.

4.2 Scanning process

As shown in table 4.1, a data sample shape printed by a 3D printing machine using selective laser sintering (SLS) was scanned by a 3D scanning machine. There are three different types of sample shape: square, cylinder, and complex shape, with the third taking the duration of time to scan.

Table 4. 1 Time Taken Scanning Process

Shape	**Time taken (min)**		
Square	7:34	6:45	7:01
Cylinder	8:16	8:38	8:56
Complex	5:11	4:42	5:25

For the first phase, each sample shape will be compared the time duration taken for 3D scanner process with the different types of shape. It is to observe the shortest time readings while using the 3D scanner with different shapes. The data of sample shape will convert to the percentage value as shown in figure 4.1.

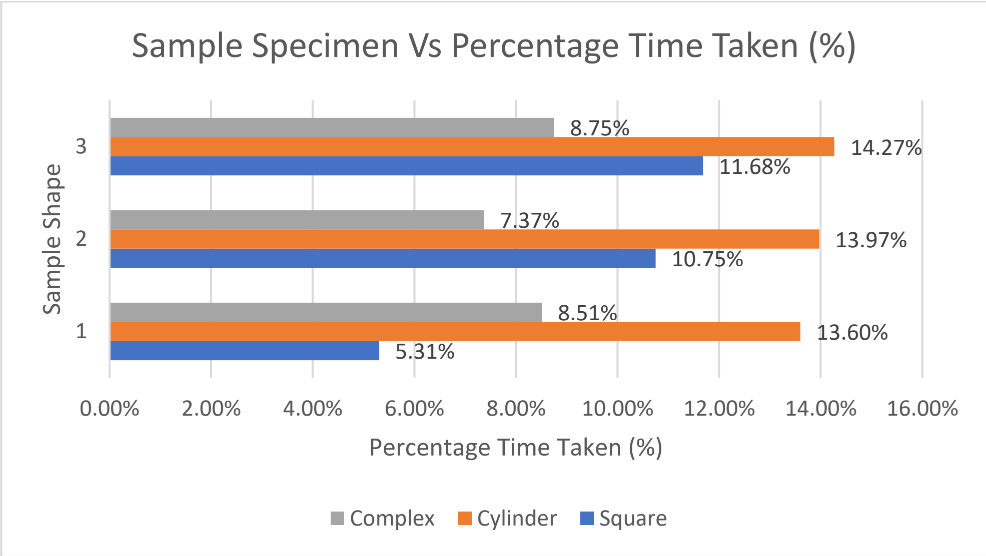


Figure 4. 1 Sample Specimen Vs Percentage Time Taken (%)

The figure 4.1 shows the outcome of the time required by the 3D Scanning Machine to scanning the sample shape. As a result, the entire time taken duration for the three takes of 3 kinds of sample specimen is around 4 minutes to 9 minutes of each. The square shape takes 6 minutes to 7 minutes, with a percentage of time taken duration ranging from 5.13 % to 11.68 %. According to the calculation below, the average percentage duration for a square shape is 9.25 %. The median percentage of time required for a square shape is 10.75 %. The difference between the highest and lowest percentage of time spent on square shapes is 6.37 %.

Square calculation:

$$\text{Mean} = \frac{5.31+10.75+11.68}{3} = 9.25\%$$

Median = 10.75%

Range = 11.68-5.31 = 6.37%

Following that, the duration of the cylinder shape takes between 8 and 9 minutes, with a percentage range of 3.60 to 14.27%. Based on the calculations below, the mean for cylinder shape is 8.37%. The median percentage of time taken for cylinder shape is 8.38%, with a 0.4 percent difference between the highest and lowest percentages.

Cylinder calculation:

Mean = $\frac{8.16+8.38+8.56}{3}$ = 8.37%

Median = 8.38%

Range = 8.56-8.16 = 0.4%

For the complex shape, the duration takes between 4 to 5 minutes, with the percentage value 7.37% to 8.75%. Based on the calculations below, the mean for complex shape is 8.21%. While the median percentage of time taken for complex shape is 8.51%, with a 1.38 percent difference between the highest and lowest percentages.

Complex calculation:

Mean = $\frac{7.37+8.51+8.75}{3}$ = 8.21%

Median = 8.51%

Range = 8.56-8.16 = 1.38%

According to the overall mean of three different shapes, the short time taken to scanning the sample shape by 3D Scanning machine is a complex shape with a range value around 1.38 percent, while the square and cylinder shapes are 9.25 percent and 8.37 percent, respectively.

4.3 Method Editing Cloud data

PolyWorks and Catia are used to edit cloud data for three types of type samples. Each kind of sample shape is edited the cloud data using that software and the analysis result is produced (Minetola, Iuliano and Calignano, 2015). Table 4.2 shows the time required to edit cloud data using both software.

Table 4. 2 Time modifying cloud data

Shape	PolyWorks (minutes)			CATIA (minutes)		
	1	2	3	1	2	3
Square	56:23	49:36	48:16	8:19	5:45	4:12
Cylinder	12.52	12.37	11.13	5:38	6:04	5:49
Complex	11:18	10:26	9:51	12:44	12.29	10.50

Figure 4.2 show the graph duration time for editing cloud data to surface modelling using the PolyWorks software. From the graph, complex sample shape is the faster duration to editing cloud data using PolyWorks software compared to the square shape. In contrast,

figure 4.3 show the graph for the editing cloud data using Catia software. From the graph, can see that the square shape is faster than cylinder and complex sample shape.

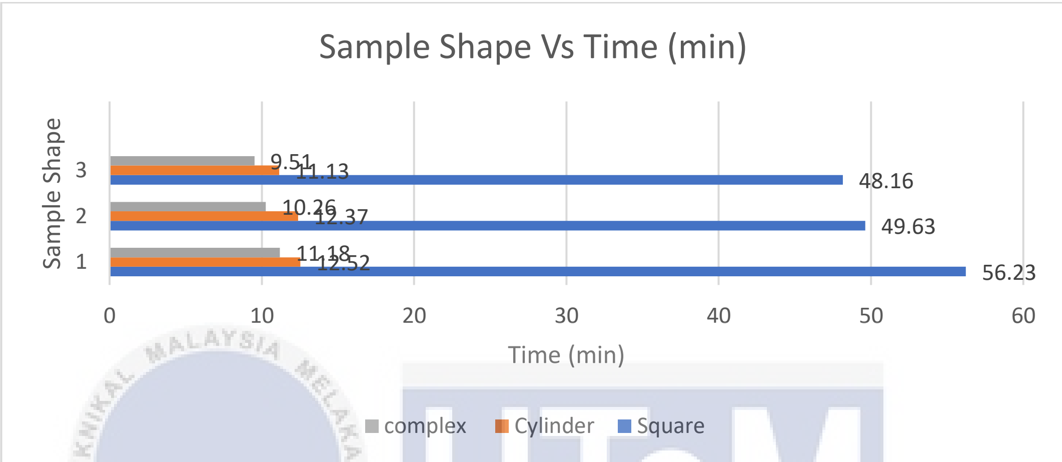


Figure 4. 2 Sample Shape cloud data duration of PolyWorks

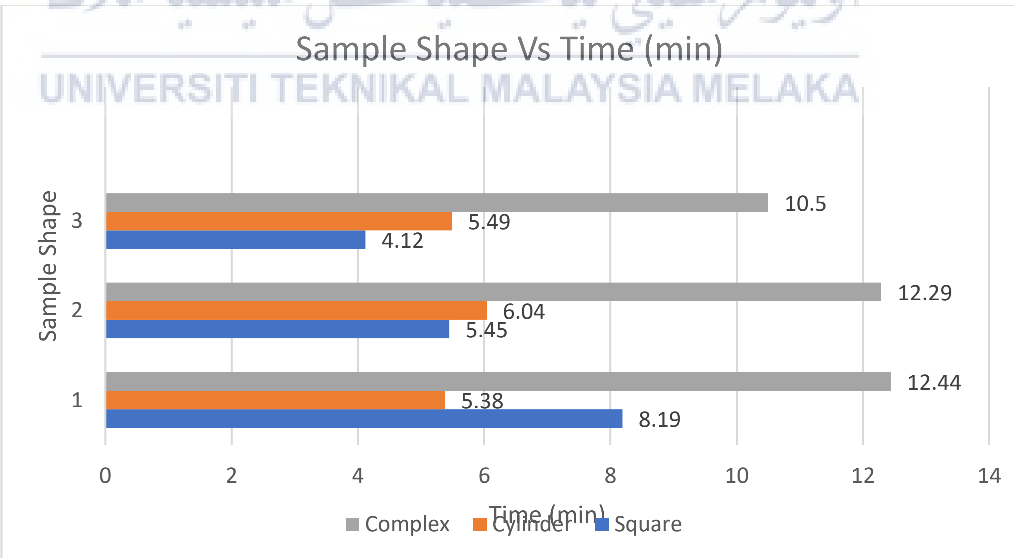


Figure 4. 3 Sample Shape cloud data duration of Catia

4.3.1 Square Shape

i. Method 1 editing cloud data using PolyWorks Software

The PolyWorks software is used to generate surface modelling from cloud data. Table 4.3 the result duration required to edit cloud data using PolyWorks Software. The average time for editing cloud data to surface modelling for square shape is 48.18 to 56.23 minutes.

Table 4. 3 Time taken square shape using PolyWorks Software

Shape	PolyWorks (minutes)		
	1	2	3
Square	56:23	49:36	48:16

Figure 4.4 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the first time takes the result duration is 56.23 minutes. The colour scale shown in figure 4.4 is the tolerance gap between original PolyWorks data and scan PolyWorks data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The greenest colour part is at middle of the

surface because that area of surface is more accurate than other area which the maximum value is 0.42 as shown in figure 4.4. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.039 as shown in figure 4.4.

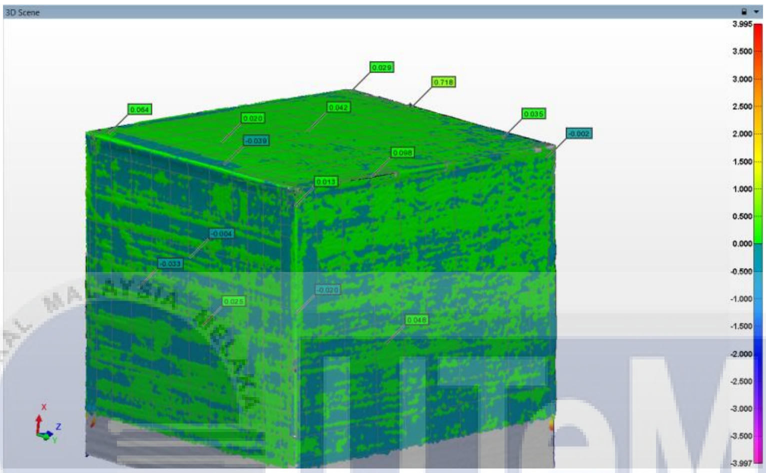


Figure 4. 4 Colour scale analysis for first square method

Table 4. 4 point analysis table for first square method

#Points	215958
Dev Mean	0.007
StdDev	0.117
Pts within +/-(1 * StdDev)	212372 (98.339%)
Pts within +/-(2 * StdDev)	214590 (99.367%)
Pts within +/-(3 * StdDev)	215085 (99.596%)
Pts within +/-(4 * StdDev)	215329 (99.709%)
Pts within +/-(5 * StdDev)	215469 (99.774%)
Pts within +/-(6 * StdDev)	215548 (99.810%)
Surface Out of Tol	0.166%

Table 4.4 shows the result of meshing part of 6 pick point at surface square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan

CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first square method analysis has overall 215958 points. The overall deviation mean is 0.007. The overall standard deviation is 0.117. The standard deviation for pick point 1 is 98.339% at point of 212372. The standard deviation for pick point 2 is 99.367% at point of 214590. The standard deviation for pick point 3 is 99.596% at point of 215329. The standard deviation for pick point 4 is 99.709% at point of 215329. The standard deviation for pick 5 is 99.774% at point 215169. The standard deviation for pick point 6 is 99.810% at point 215548. The surface out of tolerance is 0.166%. In calculation below show that the mean of the percentage of standard deviation for the first square shape method is 99.476%. The median of the percentage of standard deviation is 99.639%. The range between the highest and lowest of the percentage of standard deviation is 1.471%.

Calculation:

Mean = $\frac{98.339+99.367+99.569+99.709+99.774+99.810}{6}$ = 99.476%

Median = $\frac{99.569+99.709}{2} = 99.639\%$

Range = 99.810-98.339 = 1.471%

Figure 4.5 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the first time takes the result duration is 49.36 minutes. The colour scale shown in figure 4.5 is the tolerance gap between original PolyWorks data and scan PolyWorks data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The yellow colour part is at corner of the surface because that area of surface is more accurate than other area which the maximum value is 0.841 as shown in figure 4.5. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.393 as shown in figure 4.5.

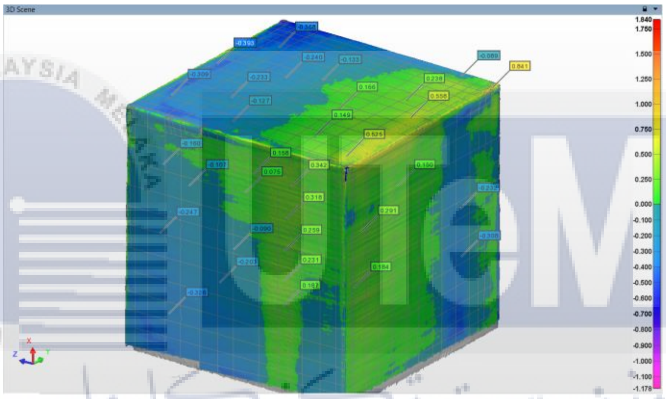


Figure 4. 5 Colour scale analysis for second square method

Table 4. 5 point analysis table for first square method

#Points	199440
Dev Mean	0.007
StdDev	0.224
Pts within +/-(1 * StdDev)	136501 (68.442%)
Pts within +/-(2 * StdDev)	190226 (95.380%)
Pts within +/-(3 * StdDev)	198495 (99.526%)
Pts within +/-(4 * StdDev)	199340 (99.950%)
Pts within +/-(5 * StdDev)	199433 (99.996%)
Pts within +/-(6 * StdDev)	199439 (99.999%)
Surface Out of Tol	1.999%

Table 4.5 shows the result of meshing part of 6 pick point at surface square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first square method analysis has overall 199440 points. The overall deviation mean is 0.007. The overall standard deviation is 0.224. The standard deviation for pick point 1 is 68.442% at point of 136501. The standard deviation for pick point 2 is 95.380% at point of 190226. The standard deviation for pick point 4 is 99.950% at point of 199340. The standard deviation for pick point 4 is 99.950% at point of 199340. The standard deviation for pick 5 is 99.996% at point 199433. The standard deviation for pick point 6 is 99.999% at point 199439. The surface out of tolerance is 1.999%. In calculation below show that the mean of the percentage of standard deviation for the first square shape method is 93.882%. The median of the percentage of standard deviation is 99.738%. The range between the highest and lowest of the percentage of standard deviation is 31.557%.

Calculation:

Mean = $\frac{68.442+95.380+99.526+99.950+99.996+99.999}{6}$ = 93.882%

Median = $\frac{99.526+99.950}{2} = 99.738\%$

Range = 99.999-68.442 = 31.557%

Figure 4.6 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the last time takes the result duration is 48.16 minutes. The colour scale shown in figure 4.6 is the tolerance gap between original PolyWorks data and scan PolyWorks data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.044 as shown in figure 4.6. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.087 as shown in figure 4.6.

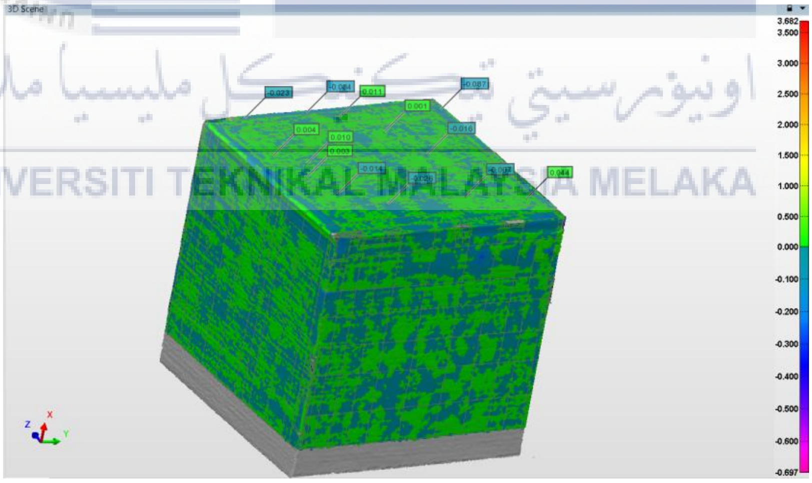


Figure 4. 6 Colour scale analysis for second square method

Table 4. 6 point analysis table for second square method

#Points	205187
Dev Mean	0.001
StdDev	0.041
Pts within +/-(1 * StdDev)	164906 (80.369%)
Pts within +/-(2 * StdDev)	195993 (95.519%)
Pts within +/-(3 * StdDev)	202180 (98.535%)
Pts within +/-(4 * StdDev)	203976 (99.410%)
Pts within +/-(5 * StdDev)	204661 (99.744%)
Pts within +/-(6 * StdDev)	204917 (99.868%)
Surface Out of Tol	0.005%

Table 4.6 shows the result of meshing part of 6 pick point at surface square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first square method analysis has overall 205187 points. The overall deviation mean is 0.001. The overall standard deviation is 0.041 The standard deviation for pick point 1 is 80.369% at point of 164906. The standard deviation for pick point 2 is 95.519% at point of 195993. The standard deviation for pick point 3 is 98.535% at point of 202180. The standard deviation for pick point 4 is 99.410% at point of 203976. The standard deviation for pick 5 is 99.744% at point 204661. The standard deviation for pick point 6 is 99.868% at point 204917 The surface out of tolerance is 0.05%. In calculation below show that the mean of the percentage of standard deviation for the first square shape method is 98.973%. The median of the percentage of standard deviation is 95.619%. The range between the highest and lowest of the percentage of standard deviation is 19.499%.

Calculation:

Mean = $\frac{80.369+95.519+98.535+99.410+99.744+99.868}{6}$ = 95.619%

Median = $\frac{98.535+99.410}{2} = 98.973\%$

Range = 99.868-80.369 = 19.499%

ii. Method 2 editing cloud data using Catia Software

Table 4.7 show the result duration required to edit cloud data to surface modelling using Catia Software. The average time for editing cloud data to surface modelling for square shape is 48.18 to 56.23 minutes.

Table 4. 7 Time taken square shape using Catia Software

Shape	**Catia (minutes)**		
	1	2	3
Square	8:19	5:45	4:12

Figure 4.7 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the first time takes the result duration is 8.19 minutes. The colour scale shown in figure 4.7 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green,

yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.638 as shown in figure 4.7. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.463 as shown in figure 4.7.

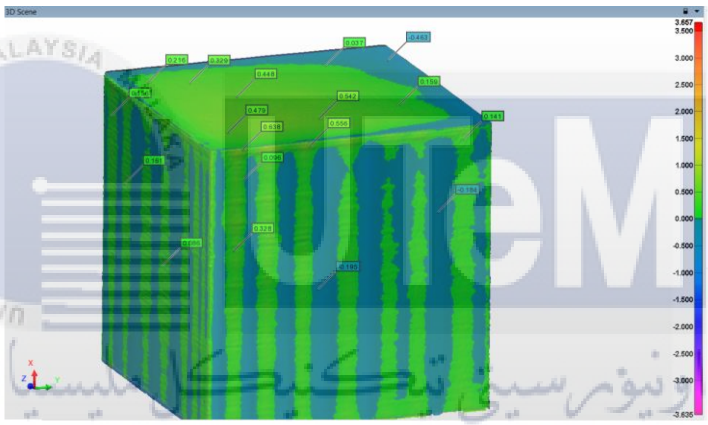


Figure 4. 7 Colour scale analysis for second square method

Table 4. 8 point analysis table for second square method

#Points	246850
Dev Mean	0.014
StdDev	0.215
Pts within +/-(1 * StdDev)	194920 (78.963%)
Pts within +/-(2 * StdDev)	232759 (94.292%)
Pts within +/-(3 * StdDev)	244073 (98.875%)
Pts within +/-(4 * StdDev)	245188 (99.327%)
Pts within +/-(5 * StdDev)	245809 (99.578%)
Pts within +/-(6 * StdDev)	246304 (99.779%)
Surface Out of Tol	3.507%

Table 4.8 shows the result of meshing part of 6 pick point at surface square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first square method analysis has overall 246850 points. The overall deviation mean is 0.014. The overall standard deviation is 0.215. The standard deviation for pick point 1 is 78.963% at point of 194920. The standard deviation for pick point 2 is 95.292% at point of 232759. The standard deviation for pick point 3 is 98.875% at point of 244073. The standard deviation for pick point 4 is 99.327% at point of 245188. The standard deviation for pick 5 is 99.578% at point 245809. The standard deviation for pick point 6 is 99.779% at point 246304 The surface out of tolerance is 3.507%. In calculation below show that the mean of the percentage of standard deviation for the first square shape method is 98.973%. The median of the percentage of standard deviation is 95.619%. The range between the highest and lowest of the percentage of standard deviation is 19.499%.

Calculation:

Mean = $\frac{78.963+94.292+98.875+99.327+99.578+99.779}{6}$ = 95.136%

Median = $\frac{98.875+99.327}{2} = 99.101\%$

Range = 99.779-78.963 = 20.816%

Figure 4.8 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the second time takes the result duration is 5.45 minutes. The colour scale shown in figure 4.8 is the tolerance gap between original PolyWorks data and scan PolyWorks data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.554 as shown in figure 4.8. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.800 as shown in figure 4.8.

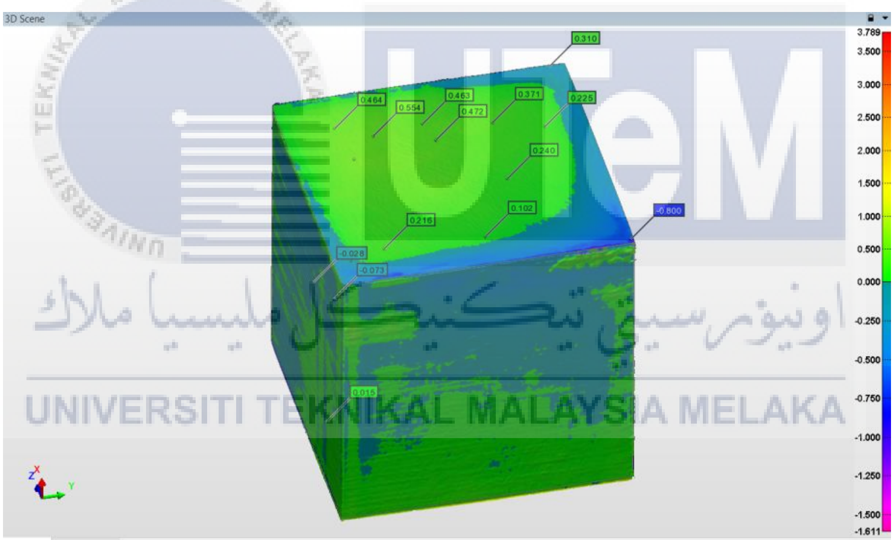


Figure 4. 8 Colour scale analysis for second square method

Table 4. 9 point analysis table for second square method

#Points	207212
Dev Mean	0.019
StdDev	0.213
Pts within +/-(1 * StdDev)	161952 (78.158%)
Pts within +/-(2 * StdDev)	195401 (94.300%)
Pts within +/-(3 * StdDev)	204252 (98.572%)
Pts within +/-(4 * StdDev)	205552 (99.199%)
Pts within +/-(5 * StdDev)	206367 (99.592%)
Pts within +/-(6 * StdDev)	207013 (99.904%)
Surface Out of Tol	2.717%

Table 4.9 shows the result of meshing part of 6 pick point at surface square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first square method analysis has overall 207212 points. The overall deviation mean is 0.019. The overall standard deviation is 0.213 The standard deviation for pick point 1 is 78.158% at point of 161952. The standard deviation for pick point 2 is 94.300% at point of 195401. The standard deviation for pick point 3 is 98.572% at point of 204252. The standard deviation for pick point 4 is 99.199% at point of 205552. The standard deviation for pick 5 is 99.592% at point 206367. The standard deviation for pick point 6 is 99.904% at point 207013 The surface out of tolerance is 2.717%. In calculation below show that the mean of the percentage of standard deviation for the first square shape method is 98.973%. The median of the percentage of standard deviation is 95.619%. The range between the highest and lowest of the percentage of standard deviation is 19.499%.

Calculation:

$$\text{Mean} = \frac{78.158+94.300+98.572+99.199+99.592+99.904}{6} = 94.954\%$$

$$\text{Median} = \frac{98.572+99.199}{2} = 98.886\%$$

Range = 99.904-78.158 = 21.746%

Figure 4.9 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the last time takes the result duration is 4.12 minutes. The colour scale shown in figure 4.9 is the tolerance gap between original PolyWorks data and scan PolyWorks data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.862 as shown in figure 4.9. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.314 as shown in figure 4.9.

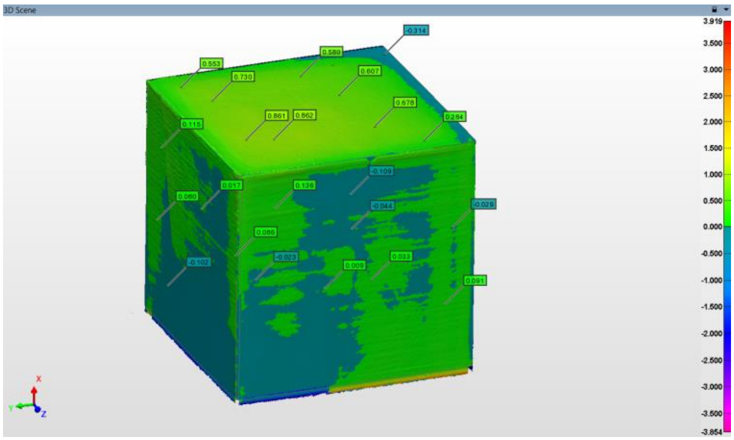


Figure 4. 9 Colour scale analysis for third square method

Table 4. 10 point analysis table for third square method

#Points	227998
Dev Mean	0.097
StdDev	0.428
Pts within +/-(1 * StdDev)	202321 (88.738%)
Pts within +/-(2 * StdDev)	222005 (97.371%)
Pts within +/-(3 * StdDev)	222879 (97.755%)
Pts within +/-(4 * StdDev)	223922 (98.212%)
Pts within +/-(5 * StdDev)	225151 (98.751%)
Pts within +/-(6 * StdDev)	226482 (99.335%)
Surface Out of Tol	14.218%

Table 4.10 shows the result of meshing part of 6 pick point at surface square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that last square method analysis has overall 227998 points. The overall deviation mean is 0.097. The overall standard deviation is 0.428 The standard deviation for pick point 1 is 88.738% at point of 202321. The standard deviation for pick point 2 is 97.371% at point

of 222005. The standard deviation for pick point 3 is 97.755% at point of 222879. The standard deviation for pick point 4 is 98.212% at point of 223922. The standard deviation for pick 5 is 98.751% at point 225151. The standard deviation for pick point 6 is 99.335% at point 226482. The surface out of tolerance is 14.218%. In calculation below show that the mean of the percentage of standard deviation for the first square shape method is 98.973%. The median of the percentage of standard deviation is 95.619%. The range between the highest and lowest of the percentage of standard deviation is 19.499%.

Calculation:

Mean = $\frac{88.738+97.371+97.755+98.212+98.751+99.335}{6}$ = 96.693%

Median = $\frac{97.755+98.212}{2} = 97.984\%$

Range = 99.335-88.738 = 10.597%

4.3.2. Cylinder shape

iii. Method 1 editing cloud data using PolyWorks Software

The PolyWorks software is used to generate surface modelling from cloud data. Table 4.11 the result duration required to edit cloud data using PolyWorks Software. The average time for editing cloud data to surface modelling for cylinder shape is 11.13 to 12.52 minutes.

Table 4. 11 Time taken square shape using PolyWorks Software

Shape	**PolyWorks (minutes)**		
	1	2	3
Cylinder	12.52	12.37	11.13

Figure 4.10 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the first time takes the result duration is 12.52 minutes. The colour scale shown in figure 4.10 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.6mm to +0.6mm. The red colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.526 as shown in figure

4.10. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.522 as shown in figure 4.10.

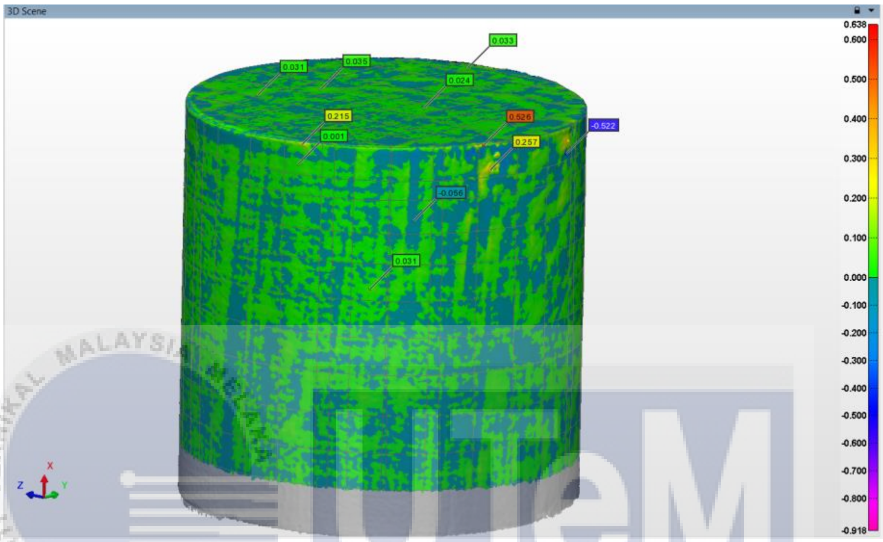


Figure 4. 10 Colour scale analysis for first cylinder method

Table 4. 12 point analysis table for first cylinder method

#Points	134464
Dev Mean	0.001
StdDev	0.045
Pts within +/-(1 * StdDev)	118255 (87.945%)
Pts within +/-(2 * StdDev)	129196 (96.082%)
Pts within +/-(3 * StdDev)	132048 (98.203%)
Pts within +/-(4 * StdDev)	133342 (99.166%)
Pts within +/-(5 * StdDev)	133899 (99.580%)
Pts within +/-(6 * StdDev)	134100 (99.729%)
Surface Out of Tol	0.018%

Table 4.11 shows the result of meshing part of 6 pick point at surface cylinder shape sample which randomly selected to show standard deviation values in percentage. The result

was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first cylinder method analysis has overall 134464 points. The overall deviation mean is 0.001. The overall standard deviation is 0.045 The standard deviation for pick point 1 is 88.945% at point of 118255. The standard deviation for pick point 2 is 96.082% at point of 129196. The standard deviation for pick point 3 is 98.203% at point of 132048. The standard deviation for pick point 4 is 99.166% at point of 133342. The standard deviation for pick 5 is 99.580% at point 133899. The standard deviation for pick point 6 is 99.729% at point 134100. The surface out of tolerance is 0.018%. In calculation below show that the mean of the percentage of standard deviation for the first cylinder shape method is 96.784%. The median of the percentage of standard deviation is 98.685%. The range between the highest and lowest of the percentage of standard deviation is 11.784%.

Calculation:

Mean = $\frac{87.945+96.082+98.203+99.166+99.580+99.729}{6}$ = 96.784%

Median = $\frac{98.203+99.166}{2} = 98.685\%$

Range = 99.729-87.945 = 11.784%

Figure 4.11 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the second time takes the result duration is 12.37 minutes. The colour scale shown in figure 4.11 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The yellow colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.755 as shown in figure 4.11. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.259 as shown in figure 4.11.

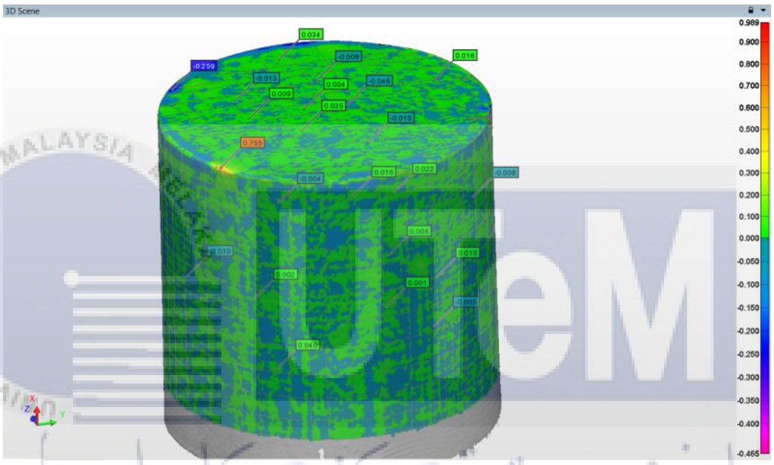


Figure 4. 11 Colour scale analysis for second cylinder method

Table 4. 13 point analysis table for second cylinder method

#Points	124689
Dev Mean	0.002
StdDev	0.037
Pts within +/-(1 * StdDev)	109226 (87.599%)
Pts within +/-(2 * StdDev)	120423 (96.579%)
Pts within +/-(3 * StdDev)	122572 (98.302%)
Pts within +/-(4 * StdDev)	123576 (99.107%)
Pts within +/-(5 * StdDev)	124066 (99.500%)
Pts within +/-(6 * StdDev)	124269 (99.663%)
Surface Out of Tol	0.010%

Table 4.13 shows the result of meshing part of 6 pick point at surface cylinder shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that second cylinder method analysis has overall 124689 points. The overall deviation mean is 0.002. The overall standard deviation is 0.037. The standard deviation for pick point 1 is 87.599% at point of 109226. The standard deviation for pick point 2 is 96.579% at point of 120423. The standard deviation for pick point 3 is 98.302% at point of 122572. The standard deviation for pick point 4 is 99.107% at point of 123576. The standard deviation for pick 5 is 99.500% at point 124066. The standard deviation for pick point 6 is 99.663% at point 124269. The surface out of tolerance is 0.010%. In calculation below show that the mean of the percentage of standard deviation for the second square cylinder method is 96.784%. The median of the percentage of standard deviation is 98.685%. The range between the highest and lowest of the percentage of standard deviation is 11.784%.

Calculation:

$$\text{Mean} = \frac{87.599+96.579+98.302+99.107+99.500+99.663}{6} = 96.792\%$$

$$\text{Median} = \frac{98.302+99.107}{2} = 98.705\%$$

Range = 99.663-87.599 = 12.064%

Figure 4.12 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the third time takes the result duration is 11.13 minutes. The colour scale shown in figure 4.12 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.25mm to +0.25mm. The yellow colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.257 as shown in figure 4.12. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.012 as shown in figure 4.12.

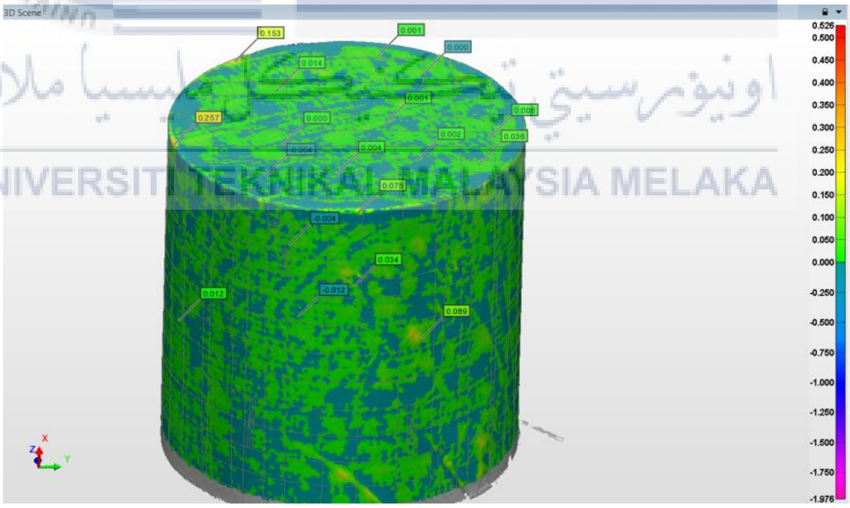


Figure 4. 12 Colour scale analysis for third cylinder metho

Table 4. 14 point analysis table for third cylinder method

#Points	116893
Dev Mean	0.002
StdDev	0.036
Pts within +/-(1 * StdDev)	97411 (83.333%)
Pts within +/-(2 * StdDev)	110767 (94.759%)
Pts within +/-(3 * StdDev)	114474 (97.931%)
Pts within +/-(4 * StdDev)	115989 (99.227%)
Pts within +/-(5 * StdDev)	116605 (99.754%)
Pts within +/-(6 * StdDev)	116768 (99.893%)
Surface Out of Tol	0.000%

Table 4.14 shows the result of meshing part of 6 pick point at surface cylinder shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that third cylinder method analysis has overall 116893 points. The overall deviation mean is 0.002. The overall standard deviation is 0.036. The standard deviation for pick point 1 is 83.333% at point of 97411. The standard deviation for pick point 2 is 94.759% at point of 110767. The standard deviation for pick point 3 is 97.931% at point of 114474. The standard deviation for pick point 4 is 99.227% at point of 115989. The standard deviation for pick 5 is 99.754% at point 116605. The standard deviation for pick point 6 is 99.893% at point 116768. The surface out of tolerance is 0.000%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 95.816%. The median of the percentage of standard deviation is 98.579%. The range between the highest and lowest of the percentage of standard deviation is 16.56%.

Calculation:

Mean = $\frac{83.333+94.759+97.931+99.227+99.754+99.893}{6}$ = 95.816%

Median = $\frac{97.931+99.227}{2} = 98.579\%$

Range = 99.893-83.333 = 16.56%

iv. Method 2 editing cloud data using Catia Software

Table 4.15 show the result duration required to edit cloud data to surface modelling using Catia Software. The average time for editing cloud data to surface modelling for square shape is 5.39 to 6.04 minutes.

Table 4. 15 Time taken square shape using Catia Software

Shape	Catia (minutes)		
	1	2	3
Cylinder	5:38	6:04	5:49

Figure 4.13 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the first time takes the result duration is 5.38 minutes. The colour scale shown in figure 4.14 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.0mm to +1.0mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.862 as shown in figure 4.13. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.314 as shown in figure 4.13.

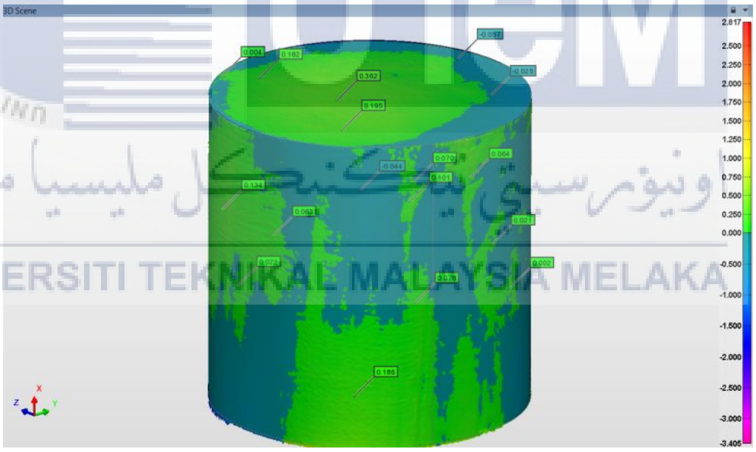


Figure 4. 13 Colour scale analysis for first cylinder method

Table 4. 16 point analysis table for first cylinder method

#Points	144625
Dev Mean	0.012
StdDev	0.179
Pts within +/-(1 * StdDev)	118472 (81.917%)
Pts within +/-(2 * StdDev)	140747 (97.319%)
Pts within +/-(3 * StdDev)	142851 (98.773%)
Pts within +/-(4 * StdDev)	143491 (99.216%)
Pts within +/-(5 * StdDev)	143817 (99.441%)
Pts within +/-(6 * StdDev)	144085 (99.627%)
Surface Out of Tol	0.359%

Table 4.16 shows the result of meshing part of 6 pick point at surface cylinder shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first cylinder method analysis has overall 144625 points. The overall deviation mean is 0.012. The overall standard deviation is 0.179. The standard deviation for pick point 1 is 81.917% at point of 118472. The standard deviation for pick point 2 is 97.319% at point of 140747. The standard deviation for pick point 3 is 98.773% at point of 142851. The standard deviation for pick point 4 is 99.216% at point of 143491. The standard deviation for pick 5 is 99.441% at point 143817. The standard deviation for pick point 6 is 99.627% at point 144082. The surface out of tolerance is 0.359%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 96.049%. The median of the percentage of standard deviation is 98.995%. The range between the highest and lowest of the percentage of standard deviation is 17.71%.

Calculation:

$$\text{Mean} = \frac{81.917+97.319+98.773+99.216+99.441+99.627}{6} = 96.049\%$$

$$\text{Median} = \frac{98.773+99.216}{2} = 98.995\%$$

Range = 99.627-81.917 = 17.71%

Figure 4.14 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the second time takes the result duration is 6.04 minutes. The colour scale shown in figure 4.14 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.75mm to +0.75mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.436 as shown in figure 4.14. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.129 as shown in figure 4.14.

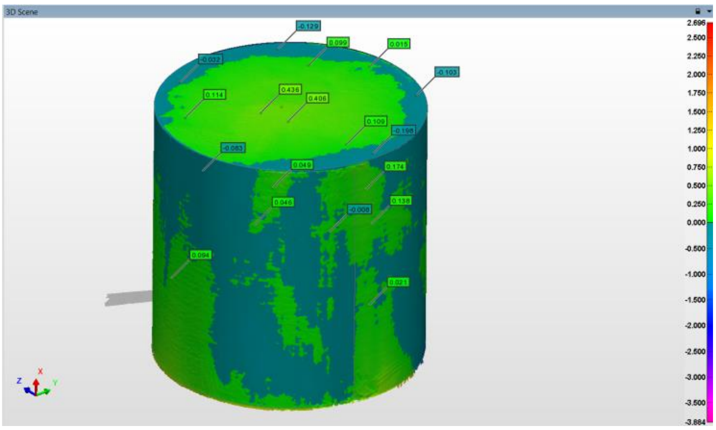


Figure 4. 14 Colour scale analysis for second cylinder method

Table 4. 17 point analysis table for second cylinder method

#Points	141908
Dev Mean	0.025
StdDev	0.178
Pts within +/-(1 * StdDev)	118140 (83.251%)
Pts within +/-(2 * StdDev)	137105 (96.615%)
Pts within +/-(3 * StdDev)	139846 (98.547%)
Pts within +/-(4 * StdDev)	140486 (98.998%)
Pts within +/-(5 * StdDev)	140906 (99.294%)
Pts within +/-(6 * StdDev)	141239 (99.529%)
Surface Out of Tol	0.481%

Table 4.17 shows the result of meshing part of 6 pick point at surface cylinder shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that second cylinder method analysis has overall 141908 points. The overall deviation mean is 0.025. The overall standard deviation is 0.178. The standard deviation for pick point 1 is 83.251% at point of 118140. The standard deviation for pick point 2 is

96.615% at point of 137.105. The standard deviation for pick point 3 is 98.547% at point of 139846. The standard deviation for pick point 4 is 98.998% at point of 140486. The standard deviation for pick 5 is 99.294% at point 140906. The standard deviation for pick point 6 is 99.529% at point 141239. The surface out of tolerance is 0.481%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 96.139%. The median of the percentage of standard deviation is 98.773%. The range between the highest and lowest of the percentage of standard deviation is 16.278%.

Calculation:

$$\text{Mean} = \frac{83.251+96.615+98.547+98.998+99.294+99.529}{6} = 96.139\%$$

$$\text{Median} = \frac{98.547+98.998}{2} = 98.773\%$$

Range = 99.529-83.251 = 16.278%

Figure 4.15 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the third time takes the result duration is 5.49 minutes. The colour scale shown in figure 4.15 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.75mm to +0.75mm. The green colour part is at around of the surface because that area of surface is accurate than other area which the maximum value is 0.413 as shown in figure 4.15. The bluest part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is -0.229 as shown in figure 4.15.

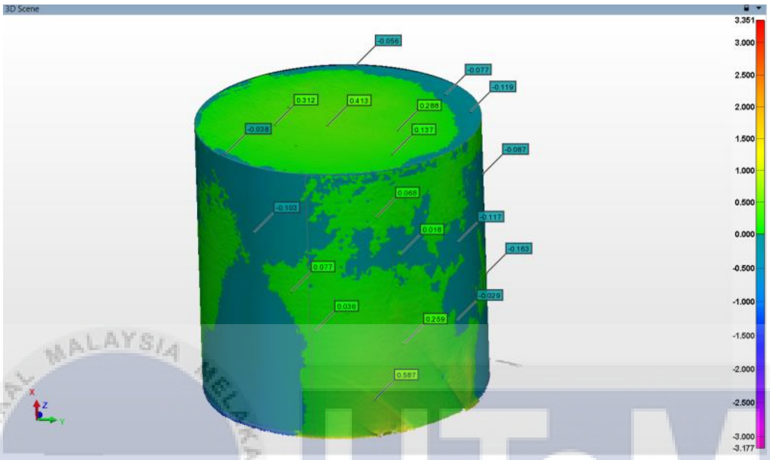


Figure 4. 15 Colour scale analysis for third cylinder method

Table 4. 18 point analysis table for third cylinder method

#Points	125296
Dev Mean	0.051
StdDev	0.247
Pts within +/-(1 * StdDev)	102688 (81.956%)
Pts within +/-(2 * StdDev)	120794 (96.407%)
Pts within +/-(3 * StdDev)	122772 (97.986%)
Pts within +/-(4 * StdDev)	123792 (98.800%)
Pts within +/-(5 * StdDev)	124434 (99.312%)
Pts within +/-(6 * StdDev)	124857 (99.650%)
Surface Out of Tol	1.571%

Table 4.18 shows the result of meshing part of 6 pick point at cylinder square shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan

CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that third cylinder method analysis has overall 125296 points. The overall deviation mean is 0.051. The overall standard deviation is 0.247. The standard deviation for pick point 1 is 81.956% at point of 102688. The standard deviation for pick point 2 is 96.407% at point of 120794. The standard deviation for pick point 3 is 97.986% at point of 122772. The standard deviation for pick point 4 is 98.800% at point of 123792. The standard deviation for pick 5 is 99.312% at point 124434. The standard deviation for pick point 6 is 99.650% at point 124857. The surface out of tolerance is 1.571%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 95.685%. The median of the percentage of standard deviation is 98.393%. The range between the highest and lowest of the percentage of standard deviation is 17.694%.

Calculation:

Mean = $\frac{81.956+96.407+97.986+98.800+99.312+99.650}{6}$ = 95.685%

Median = $\frac{97.986+98.800}{2} = 98.393\%$

Range = 99.650-81.956 = 17.694%

4.3.3 Complex shape

v. Method 1 editing cloud data using PolyWorks Software

The PolyWorks software is used to generate surface modelling from cloud data. Table 4.18 the result duration required to edit cloud data using PolyWorks Software. The average time for editing cloud data to surface modelling for cylinder shape is 9.51 to 11.18 minutes.

Table 4. 19 Time taken square shape using PolyWorks Software

Shape	**PolyWorks (minutes)**		
	1	2	3
Complex	11:18	10:26	9:51

Figure 4.16 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the first time takes the result duration is 11.18 minutes. The colour scale shown in figure 4.16 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.400mm to +0.656mm. The red colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.611 as shown in figure 4.16. The indigo part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is 0.318 as shown in figure 4.16.

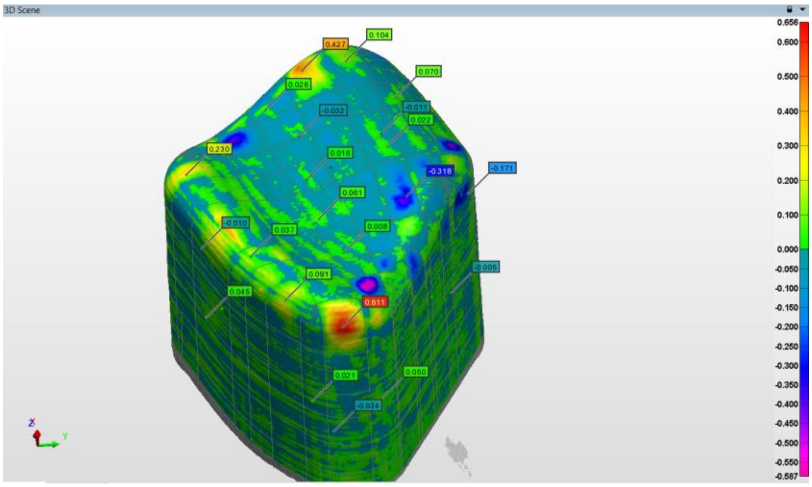


Figure 4. 16 Colour scale analysis for first complex method

Table 4. 20 point analysis table for first complex method

#Points	235401
Dev Mean	0.002
StdDev	0.072
Pts within +/-(1 * StdDev)	201136 (85.444%)
Pts within +/-(2 * StdDev)	224205 (95.244%)
Pts within +/-(3 * StdDev)	229709 (97.582%)
Pts within +/-(4 * StdDev)	232720 (98.861%)
Pts within +/-(5 * StdDev)	234010 (99.409%)
Pts within +/-(6 * StdDev)	234675 (99.692%)
Surface Out of Tol	0.134%

Table 4.20 shows the result of meshing part of 6 pick point at surface complex shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first complex method analysis has overall 235401 points. The overall deviation mean is 0.002. The overall standard deviation is 0.072. The standard deviation for pick point

1 is 85.444% at point of 201136. The standard deviation for pick point 2 is 95.244% at point of 224205. The standard deviation for pick point 3 is 97.582% at point of 229709. The standard deviation for pick point 4 is 98.861% at point of 232720. The standard deviation for pick 5 is 99.409% at point 234010. The standard deviation for pick point 6 is 99.692% at point 234675. The surface out of tolerance is 0.134%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 95.539%. The median of the percentage of standard deviation is 98.222%. The range between the highest and lowest of the percentage of standard deviation is 14.248%.

Calculation:

Mean = $\frac{85.444+92.244+97.582+98.861+99.409+99.692}{6}$ = 95.539%

Median = $\frac{97.582+98.861}{2} = 98.222\%$

Range = 99.692-85.444 = 14.248%

Figure 4.17 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the second time takes the result duration is 10.26 minutes. The colour scale shown in figure 4.17 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.50mm to +0.80mm. The red colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.781 as shown in figure 4.17. The indigo part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is 0.456 as shown in figure 4.17.

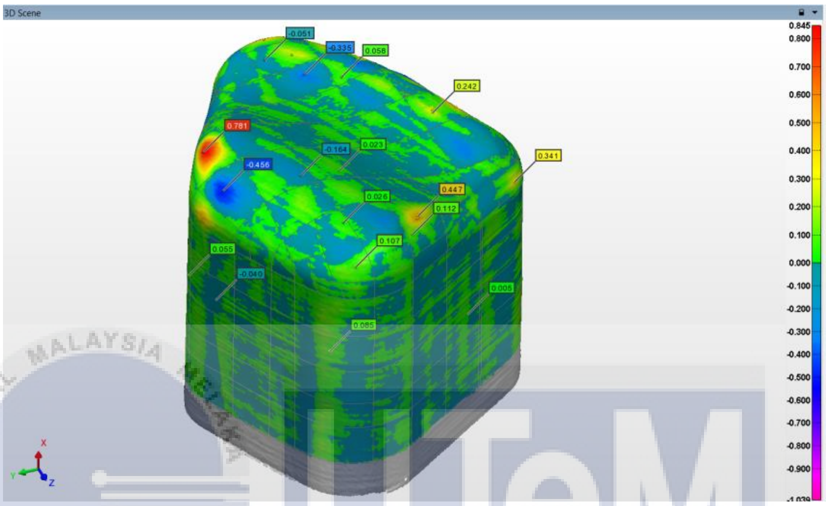


Figure 4. 17 Colour scale analysis for second complex method

Table 4. 21 point analysis table for second complex method

#Points	218980
Dev Mean	0.002
StdDev	0.089
Pts within +/-(1 * StdDev)	187802 (85.762%)
Pts within +/-(2 * StdDev)	208995 (95.440%)
Pts within +/-(3 * StdDev)	214380 (97.899%)
Pts within +/-(4 * StdDev)	216830 (99.018%)
Pts within +/-(5 * StdDev)	217902 (99.508%)
Pts within +/-(6 * StdDev)	218302 (99.690%)
Surface Out of Tol	0.263%

Table 4.21 shows the result of meshing part of 6 pick point at surface complex shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan

CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that second complex method analysis has overall 218980 points. The overall deviation mean is 0.002. The overall standard deviation is 0.089. The standard deviation for pick point 1 is 85.762% at point of 187802. The standard deviation for pick point 2 is 95.440% at point of 208995. The standard deviation for pick point 3 is 97.899% at point of 214380. The standard deviation for pick point 4 is 99.018% at point of 216830. The standard deviation for pick 5 is 99.508% at point 217902. The standard deviation for pick point 6 is 99.690% at point 218302. The surface out of tolerance is 0.263%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 96.219%. The median of the percentage of standard deviation is 98.459%. The range between the highest and lowest of the percentage of standard deviation is 13.928%.

Calculation:

Mean = $\frac{85.762+95.440+97.899+99.018+99.508+99.690}{6}$ = 96.219%

Median = $\frac{97.899+99.018}{2} = 98.459\%$

Range = 99.690-85.762 = 13.928%

Figure 4.18 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in PolyWorks software for the third time takes the result duration is 9.51 minutes. The colour scale shown in figure 4.18 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.50mm to +0.50mm. The yellow colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.432 as shown in figure 4.18. The indigo part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is 0.307as shown in figure 4.18.

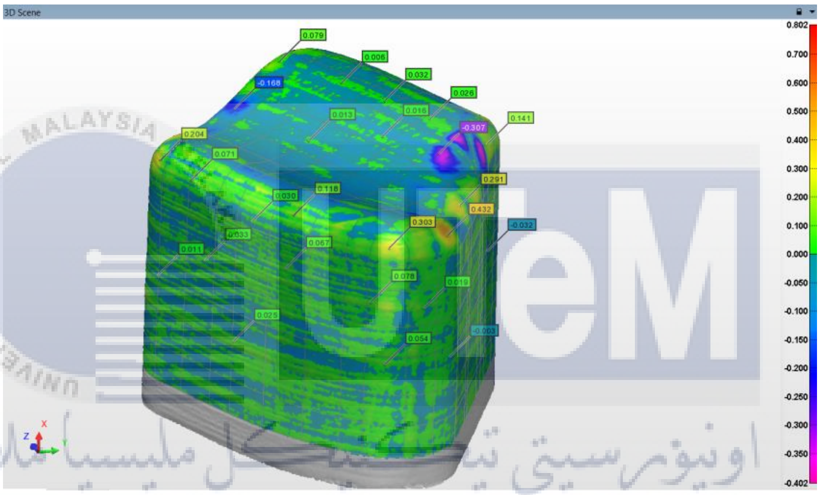


Figure 4. 18 Colour scale analysis for third complex method

Table 4. 22 point analysis table for third complex method

#Points	216963
Dev Mean	0.006
StdDev	0.077
Pts within +/-(1 * StdDev)	184414 (84.998%)
Pts within +/-(2 * StdDev)	208434 (96.069%)
Pts within +/-(3 * StdDev)	212912 (98.133%)
Pts within +/-(4 * StdDev)	214590 (98.906%)
Pts within +/-(5 * StdDev)	215556 (99.352%)
Pts within +/-(6 * StdDev)	216125 (99.614%)
Surface Out of Tol	0.219%

Table 4.22 shows the result of meshing part of 6 pick point at surface complex shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that third complex method analysis has overall 216963 points. The overall deviation mean is 0.006. The overall standard deviation is 0.077. The standard deviation for pick point 1 is 84.998% at point of 184414. The standard deviation for pick point 2 is 96.069% at point of 208434. The standard deviation for pick point 3 is 98.133% at point of 212912. The standard deviation for pick point 4 is 98.906% at point of 214590. The standard deviation for pick 5 is 99.325% at point 215556. The standard deviation for pick point 6 is 99.614% at point 216125. The surface out of tolerance is 0.219%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 96.179%. The median of the percentage of standard deviation is 98.519%. The range between the highest and lowest of the percentage of standard deviation is 14.616%.

Calculation:

Mean = $\frac{84.998+96.069+98.133+98.906+99.352+99.614}{6}$ = 96.179%

Median = $\frac{98.133+98.906}{2} = 98.519\%$

Range = 99.614-84.998 = 14.616%

vi. Method 1 editing cloud data using PolyWorks Software

Table 4.23 show the result duration required to edit cloud data to surface modelling using Catia Software. The average time for editing cloud data to surface modelling for square shape is 10.50 to 12.44 minutes.

Table 4. 23 Time taken complex shape using Catia Software

Shape	**Catia (minutes)**		
	1	2	3
Complex	12:44	12.29	10.50

Figure 4.19 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the first time takes the result duration is 12.44 minutes. The colour scale shown in figure 4.19 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.50mm to +0.50mm. The yellow colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 0.432 as shown in figure 4.19. The indigo part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is 0.307as shown in figure 4.19.

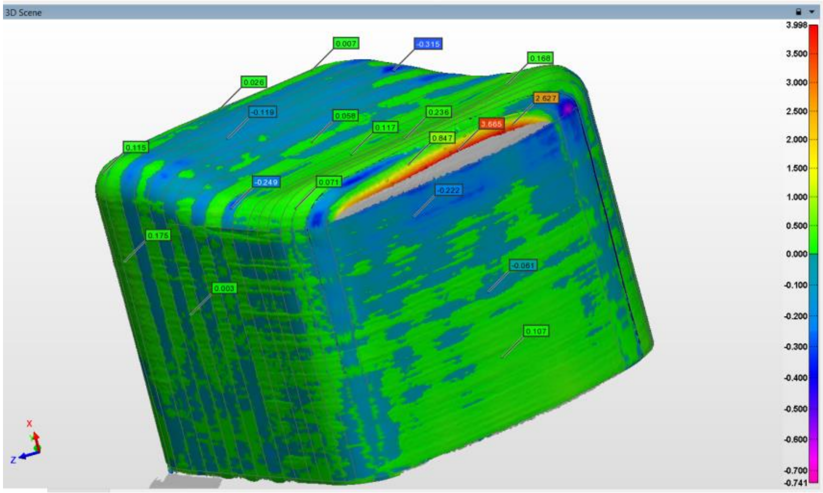


Figure 4. 19 Colour scale analysis for first complex method

Table 4. 24 point analysis table for first complex method

#Points	242591
Dev Mean	0.053
StdDev	0.252
Pts within +/-(1 * StdDev)	229066 (94.425%)
Pts within +/-(2 * StdDev)	240162 (98.999%)
Pts within +/-(3 * StdDev)	240491 (99.134%)
Pts within +/-(4 * StdDev)	240683 (99.213%)
Pts within +/-(5 * StdDev)	240884 (99.296%)
Pts within +/-(6 * StdDev)	241104 (99.387%)
Surface Out of Tol	0.632%

Table 4.24 shows the result of meshing part of 6 pick point at surface complex shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that first complex method analysis has overall 242591 points. The overall deviation mean is 0.053. The overall standard deviation is 0.252. The standard deviation for pick point 1 is 94.425% at point of 229066. The standard deviation for pick point 2 is 98.999% at point

of 240162. The standard deviation for pick point 3 is 99.134% at point of 240491. The standard deviation for pick point 4 is 99.213% at point of 240683. The standard deviation for pick 5 is 99.269% at point 240884. The standard deviation for pick point 6 is 99.387% at point 241104. The surface out of tolerance is 0.632%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 98.409%. The median of the percentage of standard deviation is 99.174%. The range between the highest and lowest of the percentage of standard deviation is 4.962%.

Calculation:

$$\text{Mean} = \frac{94.425+98.999+99.134+99.213+99.296+99.387}{6} = 98.409\%$$

$$\text{Median} = \frac{99.134+99.213}{2} = 99.174\%$$

Range = 99.387-94.425 = 4.962%

Figure 4.20 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the second time takes the result duration is 12.29 minutes. The colour scale shown in figure 4.20 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -1.00mm to +2.25 mm. The orange colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 2.210 as shown in figure 4.20. The indigo part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is 0.978 as shown in figure 4.20.

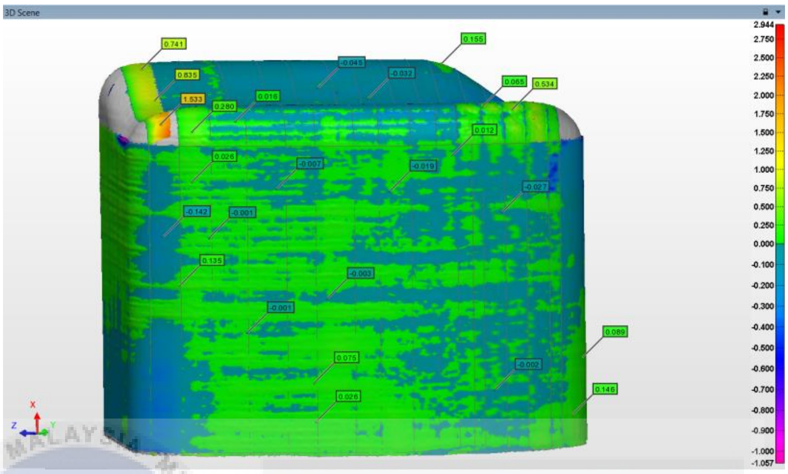


Figure 4. 20 Colour scale analysis for second complex method

Table 4. 25 point analysis table for second complex method

#Points	234126
Dev Mean	0.011
StdDev	0.180
Pts within +/-(1 * StdDev)	203894 (87.087%)
Pts within +/-(2 * StdDev)	228007 (97.386%)
Pts within +/-(3 * StdDev)	230323 (98.376%)
Pts within +/-(4 * StdDev)	231333 (98.807%)
Pts within +/-(5 * StdDev)	232650 (99.370%)
Pts within +/-(6 * StdDev)	233205 (99.607%)
Surface Out of Tol	1.568%

Table 4.25 shows the result of meshing part of 6 pick point at surface complex shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result,

can see that second complex method analysis has overall 234126 points. The overall deviation mean is 0.011. The overall standard deviation is 0.180. The standard deviation for pick point 1 is 87.087% at point of 203894. The standard deviation for pick point 2 is 97.386% at point of 228007. The standard deviation for pick point 3 is 98.376% at point of 230323. The standard deviation for pick point 4 is 98.807% at point of 23133. The standard deviation for pick 5 is 99.370% at point 232650. The standard deviation for pick point 6 is 99.607% at point 233205. The surface out of tolerance is 1.568%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 96.772%. The median of the percentage of standard deviation is 98.592%. The range between the highest and lowest of the percentage of standard deviation is 12.52%.

Calculation:

Mean = $\frac{87.087+97.386+98.376+98.807+99.370+99.607}{6}$ = 96.772%

Median = $\frac{98.376+98.807}{2} = 98.592\%$

Range = 99.607-87.087 = 12.52%

Figure 4.21 shows the result of the original CAD data and scan CAD data after fabricated in selective laser sintering (SLS) was mesh in Catia software for the third time takes the result duration is 10.50 minutes. The colour scale shown in figure 4.21 is the tolerance gap between original CAD data and scan CAD data. If positive value will show green, yellow, and red colour, while negative value will show light blue, dark blue and indigo colour. For the best result is the range of colour is between dark blue to yellow which means between -0.450mm to +2.00 mm. The yellow colour part is at corner of the surface because that area of surface is thicker than other area which the maximum value is 1.465 as shown in figure 4.21. The purple part is at outer of the surface because the area of surface is thinner than the other area which the minimum value is 0.444 as shown in figure 4.21.

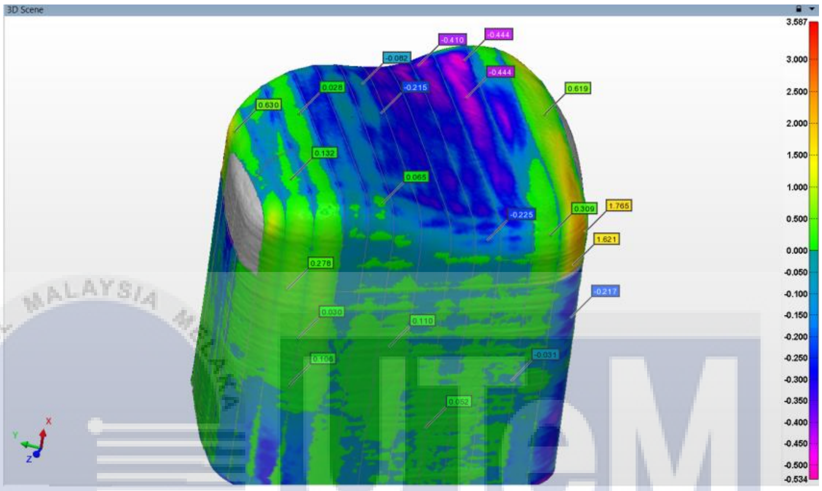


Figure 4. 21 Colour scale analysis for third complex method

Table 4. 26 Point analysis table for third complex method

#Points	219624
Dev Mean	0.030
StdDev	0.320
Pts within +/-(1 * StdDev)	193572 (88.138%)
Pts within +/-(2 * StdDev)	210846 (96.003%)
Pts within +/-(3 * StdDev)	213360 (97.148%)
Pts within +/-(4 * StdDev)	215561 (98.150%)
Pts within +/-(5 * StdDev)	217362 (98.970%)
Pts within +/-(6 * StdDev)	218832 (99.639%)
Surface Out of Tol	4.216%

Table 4.26 shows the result of meshing part of 6 pick point at surface complex shape sample which randomly selected to show standard deviation values in percentage. The result was based on the points of meshing and the tolerance between original CAD data and scan CAD data at each point was generated automatically in PolyWorks analysis. From the result, can see that third complex method analysis has overall 219624 points. The overall deviation mean is 0.030. The overall standard deviation is 0.320. The standard deviation for pick point 1 is 88.138% at point of 193572. The standard deviation for pick point 2 is 96.003% at point of 210846. The standard deviation for pick point 3 is 97.148% at point of 213360. The standard deviation for pick point 4 is 98.150% at point of 215561. The standard deviation for pick 5 is 98.970% at point 217362. The standard deviation for pick point 6 is 99.639% at point 218832. The surface out of tolerance is 4.216%. In calculation below show that the mean of the percentage of standard deviation for the third cylinder shape method is 96.772%. The median of the percentage of standard deviation is 98.592%. The range between the highest and lowest of the percentage of standard deviation is 12.52%.

Calculation:

$$\text{Mean} = \frac{88.138+96.003+97.148+98.150+98.970+99.639}{6} = 96.341\%$$

$$\text{Median} = \frac{97.148+98.150}{2} = 97.649\%$$

Range = 99.639-88.138 = 11.501%

4.4 Overall Tolerance Data Result

This research found; the result based on the 3D scanner for the study and a method for assessing the quality of as-is BIMs generated from point cloud data by analyzing the patterns of geometric deviations between the model and the point cloud data (Anil, 2013). It was expected that, the result will be collect based on 3 observed respond, it is duration scanning data (min), duration editing cloud data(min), and mean of standard deviation analysis (%). Based on the collected data, a based basic guideline was created. The function of the guideline is to observe the most optimize sample shape that has the better time duration for editing cloud data to the surface modelling and the Software is more accuracy for analysis editing cloud data to the surface modelling. Scoring method has been used to determine the best time duration of editing cloud data to surface modelling and the best software to use for the editing cloud data to surface modelling with high accuracy (Vock et al., 2019). Table 4.26 shown the result optimization for sample shape.

Table 4. 27 Result Optimization Scoring

SHAPE	CODE	TREND	SCANNING DATA TIME (MIN)	SCORE	TREND	EDITING CLOUD DATA TIME (MIN)	SCORE	TREND	STANDARD DEVIATION MEAN (%)	SCORE	SOFTWARE	TOTAL SCORE
SQUARE	A1	6	7:34	1.3	18	56:23	0.1	1	99.48	1.8	PolyWorks	3.2
	A2	4	6:45	1.5	17	49:36	0.2	18	93.88	0.1		1.8
	A3	5	7:01	1.4	16	48:16	0.3	14	95.62	0.5		2.2
CYLINDER	A4	7	8:16	1.2	15	12:52	0.5	16	95.14	0.3		2
	A5	8	8:38	1.1	13	12:37	0.6	17	94.95	0.2		1.9
	A6	9	8:56	1.0	10	11:13	0.9	3	96.96	1.6		3.5
COMPLEX	A7	2	5:11	1.7	11	11:18	0.8	4	96.78	1.5		4
	A8	1	4:42	1.8	8	10:26	1.1	5	96.79	1.4		4.3
	A9	3	5:25	1.6	7	9:51	1.2	12	95.82	0.7		3.4
SQUARE	A10	6	7:34	1.3	6	8:19	1.3	11	96.05	0.8	Catia	3.4
	A11	4	6:45	1.5	3	5:45	1.6	10	96.14	0.9		4
	A12	5	7:01	1.4	1	4:12	1.8	13	95.69	0.6		3.8
CYLINDER	A13	7	8:16	1.2	2	5:38	1.7	15	95.54	0.4		3.3
	A14	8	8:38	1.1	5	6:04	1.4	8	96.22	1.1		3.6
	A15	9	8:56	1.0	4	5:49	1.5	9	96.18	1.0		3.5
COMPLEX	A16	2	5:11	1.7	14	12:44	0.5	2	98.41	1.7		3.9
	A17	1	4:42	1.8	12	12:29	0.7	6	96.77	1.3		3.8
	A18	3	5:25	1.6	9	10:50	1.0	7	96.34	1.2		3.8

Trend Scoring:

Trend	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Score	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1

According to the outcome optimization scoring in figure 4.27, two methods share the highest score: complex shape sample using PolyWorks software and square shape sample using Catia software. The total highest scores of both are 4.

The highest score for editing cloud data to surface modelling by using PolyWorks software is the complex shape sample with the total score 4.0 compared to the lowest score is 1.8 for the square shape sample. The result is obtained from the duration of the scanning data sample, editing cloud data, and standard deviation (mean) of analysis data. The duration for scanning the data sample is 5.11 minutes. While for the duration editing cloud data to surface modelling is takes 11.18 minutes. Following that, the scanning sample is combined with the editing cloud data sample to analyse the level of accuracy using PolyWorks software, and the outcome is calculated for the standard deviation (mean). The level accuracy of complex shape in mean of percentage standard deviation is 96.78%.

In contrast, for the Catia software the highest score for editing cloud data to surface modelling also 4.0 but the lowest score is 3.3. Square shape sample is the highest score for Catia software while the cylinder shape sample is the lowest score. From the result optimization obtained, the duration of the scanning data is 6.45 minutes and the duration for the editing cloud data to surface modelling is takes 5.45 minutes. From that, the calculation of the accuracy level for complex shape in mean of percentage standard deviation is 96.14%. The close relationship between digitization and rapid prototyping methods allows for the successful use of these new approaches for the solution of difficult technical procedures

The overall data show that the best software for the editing cloud data to surface modelling using PolyWorks and Catia software is depends on the designs type of the sample shape itself. The design types and the technique to editing data cloud using both software is the most importance thing to gets the best result (Barbero and Ureta, 2011). The interconnection of these two techniques led to the main goal of reverse engineering – to create a virtual model based on real-world parts that will be used for future modifications or production (Dúbravčík and Kender, 2012).

Form that, can conclude that the best method duration for editing cloud data to surface modeling for PolyWorks software is complex shape, while the best duration for editing cloud data to surface modelling for Catia software is square shape.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This report highlights to the analyse a few designs software and compare the best method duration time for conversion cloud data to surface modelling using 3D scanning method. The introduction of this topic can deliver a thorough application of 3D scanner with reverse engineering in engineering fields based on the research obtain. As a result, this research can serve as a target for identifying problems that may emerge throughout the procedure. Following that, a literature research study is quite beneficial in obtaining all the relevant data about this project.

Similarly, the 3D scanner function, reverse engineering theory, and the surface construction process are all inextricably linked. In methodology, the process flow chart describes the process from start to finish. The benefits of this flow chart may aid in the organisation of the process. This chapter also goes into further detail about each procedure. The fabrication of the sample shape mould prototype is new experience by using 3D printing machine which is use Selective Laser Sintering (SLS) machine and use 3D scanner machine which is Steinbichler LV 3D Scan. The 3D scanner and design software used in this experiment may be identified at this point.

The first contribution of this study is on developing a method conversion data of point cloud data from 3D scanner to CAD data. This method conversion data point from 3D scanner to CAD data are applied on PolyWorks software. PolyWorks software able generate the each of point cloud data of each sample shape using 3D scanner and convert the point cloud data to CAD data. The software is suitable to use for conversion data of point cloud same as the main of main objective.

The second contribution of this study is to scan cloud data and analyse the sample shape which is square and cylinder shape or can called as geometry shape and another sample shape is complex shape by using 3D scanner. In addition, this sample shape is fabricated from Selective Laser Sintering (SLS) machine. All the sample shape are analysed by PolyWorks software after the editing cloud data from point cloud data to surface modelling method done. The sample shape result of each process by the analysis of colour scale, surface out of tolerance in percentage, graph of standard deviation in percentage and calculation of mean, median and range were done to see the different view of result that make the best precision and accuracy of analysis result

The last contribution of this study analyse is for further investigations between a few designs software and compare the best method duration time for conversion cloud data. The design software is use in this study is PolyWorks and Catia software. From the end of result, the best method duration of PolyWorks and Catia software based on method between scanning sample shape, editing cloud data to surface modelling and calculation mean of standard deviation in percentage of the accuracy result is proven that achieved the objective of this project For the PolyWorks software, the best method duration for editing cloud data to surface modelling is a complex shape, whereas the Catia software is a square shape.

Overall, the research presented in this thesis has succeeded in making a contribution to understanding the Comprehensive Study On 3d Scanner Method to Convert Cloud Data to Surface Modelling. Future research works in this direction will focus on investigation of automation of surface modelling techniques, and the possible combination of multiple techniques to improve the scanning efficiency and accuracy.

5.2 Recommendation for future work

The recommendation to further improvement present research work is as summarized below:

1. Determining the information requirements for each application, including the building features to be captured and the needed level of detail (LOD) for the captured element using a 3D scanner.
2. Study of the precision and accuracy to get the best fit data from the scanning result and the analysis result.
3. Try to use another technique method for editing the cloud data process to get the better result compare with the current result.
4. The different type of designs specification sample shape needs to use try for more experience in editing cloud data and compare the result with the current sample shape.

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APPENDICES

APPENDIX 1 GANTT CHART PSM 1

Project title	Comprehensive Study On 3D Scanner Method to Convert Cloud Data to Surface Modelling	**Faculty**	Faculty of Eng. Tech. and Manufacturing
Supervisor name	Mohammad Rafi bin Omar	**Project start**	**15** March 2021
Student name	Nurulain Nabilah Binti Azman (B091810210)	**Project end**	15 January 2022 (expected date)

	TASK ID	TASK	%DONE	WEEK 1	2	3	4	5	6	7	8	9	10	11	12	13	14
INTRODUCTION	1.0	INTRODUCTION	100%									MID SEMESTER BREAK					
	1.1	PROJECT OVERVIEW	100%														
	1.2	PROBLEM STATEMENT	100%														
	1.3	RESEARCH OBJECTIVE	100%														
	1.4	SCOPE OF RESEARCH	100%														
LITERATURE REVIEW	2.0	LITERATURE REVIEW	100%														
	2.1	INTRODUCTION	100%														
	2.2	GENERAL OVERVIEW 3D PRINTER	100%														
	2.3	GENERAL OVERVIEW 3D SCANNER	100%														
	2.4	REVERSE ENGINEERING APPLIED	100%														
	2.5	SOFTWARE CONSTRUCTION	100%														
	2.6	COMPARISON OF DIMENSIONAL AND TIME METHOD OF PRODUCT	100%														
METHODOLOGY	3.0	METHODOLOGY	100%														
	3.1	SAMPLE PREPARATION	100%														
	3.2	SAMPLE PRODUCT	100%														
	3.3	SCANNING PROCESS	100%														
	3.4	EDITING CLOUD DATA	100%														
PSM 1 SUBMISSION																	
PSM 1 PRESENTATION																	

APPENDIX 2 GANTT CHART PSM 2

	TASK ID	TASK	%DONE	WEEK													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
RESULT & ANALYSIS	1.0	INTRODUCTION	100%									MID SEMESTER BREAK					
	2.0	SCANNING PROCESS	100%														
	3.0	METHOD EDITING CLOUD DATA	100%														
	4.0	OVERALL TOLERANCE DATA RESULT	100%														
CONCLUSION & RECCOMENDATION	6.0	CONCLUSION	100%														
	7.0	RECOMMENDATION FOR FUTURE WOK	100%														
PSM 2 SUBMISSION																	
FOUR-PAGES SUMMARY SUBMISSION																	
PSM 2 PRESENTATION																	
THESIS SUBMISSION																	

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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SESI PENGAJIAN: **2020/21 Semester 1**

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