IMPROVING THE ACCURACY OF OPEN SOURCE 3D SCANNING MACHINE

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A report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project entitled “Improving the Accuracy of Open Source 3D Scanning Machine” is the result of my own work except as cited in the references.

Signature : …………………………………

Name : NADIA ILYSA BINTI RASIMAN

Date : …………………………………

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical in Engineering (Design and Innovation).

Signature : …………………………………………………..

Name of Supervisor : ……………………………………………….

Date : …………………………………………………..

ABSTRACT

In this project, Microsoft Kinect was used as a medium of low cost 3D scanner where the Kinect Xbox 360 was used as a measuring device to scan the frame scene of an object. The objectives of this experiment were to generate the new concept of a low cost active 3D scanner, analyze its structure by using finite element analysis and to produce detail design by using solid modeling software. An engineering design methodology was used as an approach to generate this new concept design. In this method, a brainstorming approach was used to obtain the design with the conceptual design and its specification. Morphological chart was used to generate few design and by using Pugh chart method analysis, the concept design comes out with final conceptual design of rotating platform with complete engineering design characteristic. This platform was used to place the Kinect Xbox which will moves into 360 degree to capture the different types of object in order to analyze the accuracy. Whereby, this accuracy of each data was obtained by using calculation of percentage difference between real object and scanned object. Skanect software was used to capturing the full color of 3D model, where this open source software will transforms Microsoft Kinect into low cost 3D scanner and able to create 3D meshes. From the result, sport shoes has the highest percentage difference of 8.6% followed by chair with 6.25% and the lowest was the shoes box with 1.6%. Thus the present of the open source software and hardware, this Kinect Xbox 360 sensor was able to be used as low cost 3D scanner and by implement the technique of moving sensor can reduced the percentage difference which can make the values near to accurate.

ABSTRAK

Didalam projek ini, Microsoft Kinect merupakan medium yang digunakan sebagai satu peranti pengimbas 3D yang murah dengan mengunakan Kinect Xbox 360 sebagai alat pengukur untuk mengimbas objek. Tujuan utama projek ini ialah untuk merekabentuk satu konsep baru yang berkaitan kepada peranti pengimbas 3D yang murah dan mengkaji struktur konsep tersebut mengunakan analisis unsur terhingga dan seterusnya menghasilkan satu lukisan lengkap mengunakkan perisisan permodelan perpejal. Kaedah yang digunakan dalam projek ini menjurus kepada kaedah lukisan kejuruteaan dimana proses ini bermula daripada menyenaraikan semua idea yag berkaitan dengan projek. Seterusnya, konsep carta morfologi telah diketengahkan untuk menghasilkan beberapa konsep baru dan melalui beberapa konsep baru ini, satu analisis yang dipanggil carta pugh telah dibuat untuk menganalisis konsep yang paling sesuai untuk digunakan dalam projek ini. Setelah itu, konsep baru ini akan digunakan untuk meletakkan Kinect Xbox 360 ini untuk mengimbas bebrapa objek yang statik pada 360 darjah pusingan. Skanect merupakan medium yang digunakan untuk memproses objek ini didalam bentuk maya dalam 3 dimensi.Skanect merupakan satu perisian yang bersifat terbuka dimana perisian ini akan digunakan untuk mengubah fungsi Microsoft Kinect kepada peranti pengimbas 3D yang murah untuk mengimbas keseluruhan data objek termasuk warna asal objek tersebut. Daripada hasil kajian, kasut sukan mempunyai nilai perbezaan yang tinggi antara ukuran asal dan ukuran daripada peranti pengimbas iaitu 8.6% ikuti oleh kerusi dengan nilai 6.25% dan nilai yang terendah merupakan kotak dengan nilai dapatan sebanyak 1.6%. Secara konklusinya, dengan mengunakkan konsep mengerakkan peranti pengimbas dengan mengerakkan secara 360 darjah mengelilingi objek dapat mengurangkan kadar perbezaan antara ukuran asal dan ukuran daripada peranti pengimbas tersebut.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Three dimension scanners (3D scanner) is a device that analysis object or environmental data. The data will be interpreted to produce three dimensional models. The first 3D scanning technology was created in the 1960s whereby early scanners used cameras, projectors and lights (Ebrahim, 2014). Due limitations to scan the object accurately, this scanners were replaced by using white light, shadowing and lasers to captured an object's surfaces after 1985. First application of this 3D scanning is used in capturing human for animation industry by using Head Scanner. However, during this time, even the 3D scanner were developing in high detail scanners, still the degree and accuracy were still hard to achieve.

Nowadays, 3D scanning technology development offers users to capture objects in and outside during the days or night. Even, the Direct Dimension successfully scanned entire airplanes, ships and historic monuments. However, the recently product 3D scanner is too expensive. Moreover, the resolutions of a scanners is limited by the resolution of hardware which affects the depth accuracy of the object's surface (S.M.Emam et al, 2014). Thus, a Kinect sensor was introduced as a low cost 3d sensor scanning. This sensor was used in animation whereby it can provide the depth of the surface.

This Kinect sensor consists of color VGA video camera, depth sensor and multi-array-microphone. It works by inferring body position in two-stage process. This process is by direct compute a depth map and by inferring body position. This data can be stored and generate the 3D model in digital form by manipulating using computer programs.

1.2 PROBLEM STATEMENT

3D scanning technologies nowadays are way too advanced. It comes with high resolutions colors and even exists in portable shapes. However, these high technologies come with high price. This will be the problems for a small company to develop products. They tend to spend a lot of money to buy this kind of technologies. Considering for educational purpose, it is a waste to spend too much money for an expensive 3D scanner machine since in educational purposes, this machine only used to exposed students to know how this machine works and its real applications. Seeing that fact, having a low cost 3D scanner is enough for an educational purpose.

Besides, software is needed to deliver raw scan data. This software is crucial for enabling user to process the data obtained from the 3d scanner. A good software will exposed the user to minimize the spent data processing which makes it more efficient. However, the present software is costly and difficult to use. Mostly the software is designed for engineering or surveyors. Thus, it is not user friendly for the non-engineering sectors. Hence, a remodeling new model to more users friendly needs to be considered.

Next, to obtain 3D scanned object, it needs much work. To get a complete surface of object, the scanning requires distinct range images which must be taken from different viewpoints to measure object with a high quality range data(Martins et al, 2005). Each viewpoint must be properly defined. This viewpoint needed to be combining to form one complete 3D model before converting it into CAD format. Thus, by designing 360 degree rotating platform for scanned object can save time and better results.

1.3 OBJECTIVE

The objectives of this project are:

- To generate new design concept of a low cost active 3D scanner.
- To analyze the structure of the low cost 3D scanner using finite element analysis.
- To produce detail design of 3D scanner using solid modeling software.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. Microsoft Kinect will be used to capture and detect the object's surface.
2. CATIA will be used as the Computer Aided Design (CAD) drawing. This software will analyze the structure of model object by using Finite Element Analysis (FEA).
3. A rotating platform will be used to place an object to be captured by 3D scanner. This motion will manipulate and generate 3 dimensional models.

1.5 GENERAL METHODOLOGY

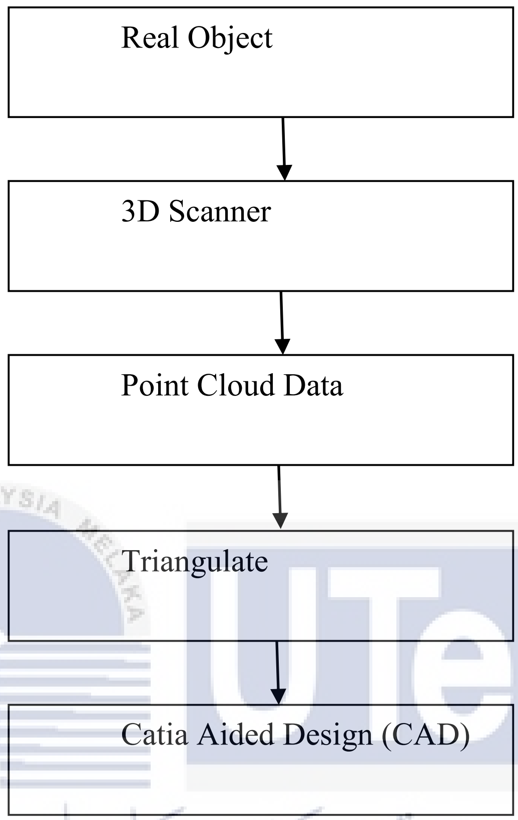

Figure1. Flowchart of Methodology of 3D Scanning Process.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nowadays, 3D scanners have become more popular and widely used tools. One of its widely field applications are in manufacturing industry, and in reverse engineering. In reverse engineering, these 3D scanners were used to create automotive parts. Basically these devices work to capture a two-dimensional object as an input and will produce a virtual three-dimension object as an output. The data captures were in points which known as point cloud. In detail, these devices will capture the depth of the object and produce a large number of points on the surface of the object. Later, the Standard Tessellation Language (STL) format will be produced by this point cloud whereby, this STL file only describes the surface geometry of the three-dimensional object without considering the colors and textures. Apparently, these devices were capable of representing virtual object with high good accuracy (Reyes et al, 2013). However, the price was extremely expensive making students or academic staffs less affordable to buy and use these devices either in academic or researcher purposed. Thus, a low cost 3D scanner will be proposed and design by using Microsoft Kinect as the 3D sensing device. In this design, some modification is made to make this Microsoft Kinect sensors act as an active 3D scanner. All the information is studied on how to improve the accuracy of this low-cost 3D scanner.

2.2 REVERSE ENGINEERING

Reverse engineering can be referred as consideration of the part objects on how it works in order to enhance or duplicate the objects. However, in 3D scanning, this reverse engineering refers to a process obtaining geometric shape from discrete sample. This discrete sample will be used to create mathematical models the CAD model does not exists. During this process, the product part is produce by extracting surfaces or sketches from the scanned object by using mesh or point cloud. Simply put, this reverse engineering in 3D scanning can produce three-dimensional model even without existing CAD files. The accuracy of the output can achieve up to 100 %. The output files can be transfer to any CAD and this output files can be function as inspection, tool path making, inspection or 3D printing and additive manufacturing.

Basically, the three-dimensional geometry for reverse engineering studies is focuses on distances or images (Herraez et al, 2016). S.M. Emam et al. (2014), have proposed a dithering technique (DT) to improve the accuracy of the laser scanning for three dimensional model reconstruction. This technique used an approach of distance through small movement of either the sensing array or the object and rescanning, and normally applied in signal and image processing application to reduce the amount of the error in the reference image. This DT method reduced the round off error by adding an external noise during the point cloud process. S.M.Emam et al. (2014), proposed this technique on the laser triangulation scanner by shifting the sensing array during capturing the scene. An experiment was carried out by using Sony XC-555P of 7681 (H) and 576(V) pixel with 8.33um pixel size. The output of depth reconstruction was studied by moving the camera sensor into two different positions. Results from the constructed depth were calculated to obtain the experimental depth value. Later, this value was compared with the actual value by using Coordinate Measuring Machine (CMM) with 0.001 mm accuracy. The results show that the accuracy of construction is improved by 50% relative a normal style acquisition.

In reverse engineering process, both software and hardware are needed to work as a team. Whereby, the hardware is used to measure the object and the software is used to create the three-dimensional virtual object. L.M.Galantucci et al. (2015) have implement motorized movements on CNC milling machine which the system is controlled by using Mach3 CNC software. A semi-automatic low cost motorized active 3D slit laser scanning system is used and this 3D scanner is focuses on its development and implementation through a several testing and experiment. This study shows a relation between hardware of the milling machine (Mach3) and the scanning software of David-LaserScan using an active sensor which is CMOS sensor. Through this experiment, the 3D scanning system can make full 360° rotation scan of the objects. An algorithms code is produce by using Processing software which this algorithm will send a command to David and Mach3 software to control the movements of the CNC machine. From several experimental methods, the accuracy of measurement can be improved by increasing the triangulation base (B1 const) (Figure 2.1) or by using larger sensor.

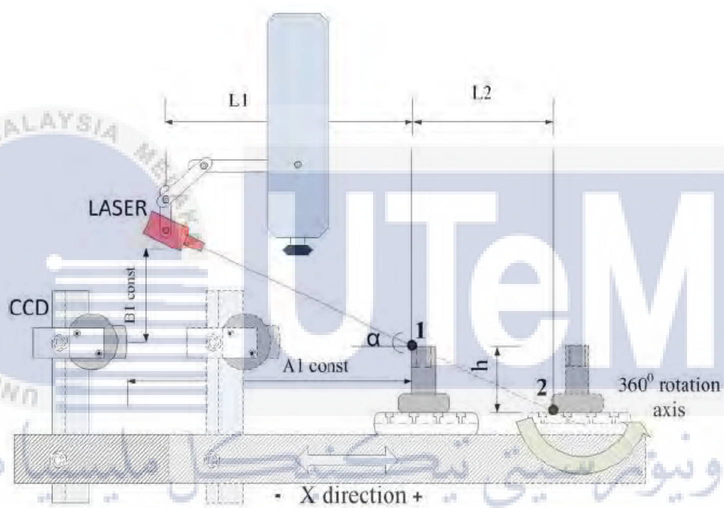

Figure 2.1 Experiment Set-up of Scanning Process.

Sansoni et al. (2005) also have described the rapid prototyping and reverse engineering of 3D optical scanner in automotive history. Sansoni et al. (2005) study shows that how 3d scanner camera and some suitable data modeling can be helpful in reverse engineering in the virtual representation and complex geometry. A Ferari 25MM model was used to produce car body by using non-contact gauging instead of using contact probes. The acquisition of the Ferari was performed by using 280 views at medium resolution. Later, OPL-3D was configured at high resolution to obtain more detail of the car body such as handles and window border. In order to create the replica body, the Ferari was mesh into 1:10 scaled. The result model was accurate and the measurement of distance between the selected triangle pair using triangulation process is acceptable.

2.3 3D SCANNING SYSTEM

3D scanner is a device that captures two dimensional object data and this data will be used to construct digital three dimensional objects. The data collected was based on the shape geometry without considering the colors of objects. This device commonly used widely in manufacturing, rapid prototyping, reverse engineering and even extensively used in production industry for gaming purpose. Back in 1998, the 3D scanning systems were revealed to be expensive, slow and low resolution (Daanen & Ter Haar, 2013). During this year, the available 3D scanners were only based on laser scanning system, patterned light system, and streophotogrammetry system (Daanen & Ter Haar, 2013). Later, when these devices were progressively increased, new techniques were introduced. The techniques are based on millimeter waves system and infrared waves system. However, in last decade, the use of streophotogrammetry was replaced to scanner laser due to its intensive and accuracy of the data provided (Herraez et al, 2016). Recently, laser scanner is the most preferable tools to be used in many disciplines of works. This devices offers short time in collecting data in engineering works and even in reverse engineering (Herraez et al., 2016). This laser scanner is work by using laser line systems where a laser line is projected on the body from variance of sides and viewed by camera under fixed angle. This system was contributed to reduction of cost and high resolution (Daanen & Ter Haar, 2013). However, this system having some problems in data gathering, data processing and in terms of accuracy (Herraez et al., 2016). Differs from structured light system, this system projects an entire pattern and accurate compute on how the 2D lines transform into 3D surface. This sequential 3D line will form complete three dimensional images. This structured light scanner consist of camera with filter, pattern projector and additional camera to capture the true colors of the 3D scene (Daanen & Ter Haar, 2013). Both of this laser and structured light are classified as an optical measurement of 3D scanning method. This optical measurement method can be classified (Figure 2.2) into two different types which is active method and passive method.

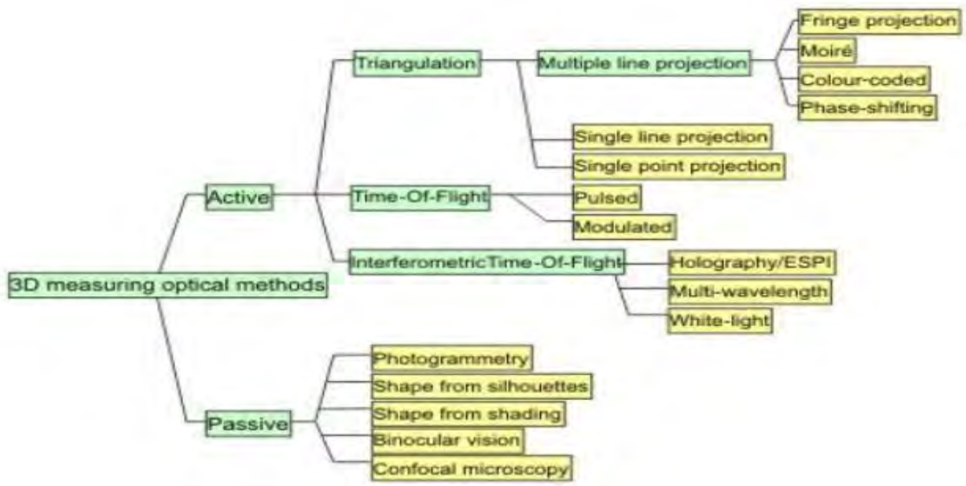

Figure 2.2 Classification of 3D Measuring Optical Method.

2.3.1 ACTIVE METHOD

Active 3D measurement method is a process which employs structure illuminations. This method is categorized as non-contact active optical 3D scanner. Bianco et al. (2013) have conducted an experiment to compare of 3D reconstruction data between active and passive method for underwater conditions. This comparison was conducted under the condition of poor visibility in a laboratory in turbid water by using structured light technique. As for active method, an active stereo technique was used by using hardware which is spatial, time, spectrum discrimination and polarization. From the result, the point cloud obtained from the active stereo technique gives more stables results in turbidity compared to passive stereo technique. In active 3D measurement method, it is require additional measurement to obtain the projected image data and controlled illumination process can be applied to overcome some overlapping image data. This illumination process is referred as structured light illumination (SLI) process. This SLI process is classified as non-contact active 3D triangulation based techniques whereby this process is has similar concept with stereo vision and is used to reduce the computational complexity of similar pixels across the camera view. This complexity is reduced by changing the positions of camera component with a projector that produces a series of stripped patterns. The derivation data between the camera and projector pixel can be analyze by changing of the pattern at certain point. Basically, this 3D triangulation based technique is known for its low cost and high accuracy result.

2.3.2 PASSIVE METHOD

Passive method is also classified into non-contact optical 3D scanner. This non-contact offers a faster way in scanning object by collecting thousands of point cloud of an object at one time. In contrast with active method, this passive method is based on stereo vision which is more convenient and more applicable due to its less apparatus setup (Muquit, Shibahara, & Aoki, 2006). This passive measurement method only acquire one move or still camera to measure the image data. However, in this 3D measurement of using stereo vision, it is found that it is hard to find accurate corresponding image which makes it become poor to reconstruct the quality of projected image. Abdul et al. (2006) experiment on the 3D reconstruction by using passive 3D measurement method shows a successful result. During the 3D reconstruction, the projection matrices obtained from the camera and about 4000-5000 of corresponding points were used to reconstruct the real object. In this case, the reconstruction accuracy of a passive method system is observed and was compared to the light structured light projection. From the comparison with the structured light projection, the passive method data achieve 0.5mm accuracy in 3D measurement even with the narrow baseline stereo camera head.

Figure 2.3 3D Reconstruct Face Data From Different View of Angle.

Multi-image photogrammetry is one of the passive methods which commonly used for human body measurement. This method utilizes multiple images acquired from multiple directions of the set up camera. The resulting point cloud of each different image is compute by the matching algorithms. In order to compute the 3D coordinates of human body measurement, a ray intersection is made to produce a dense 3D point cloud (Figure2.5). Figure 2.4 shows the result from the passive method of the intersection ray.

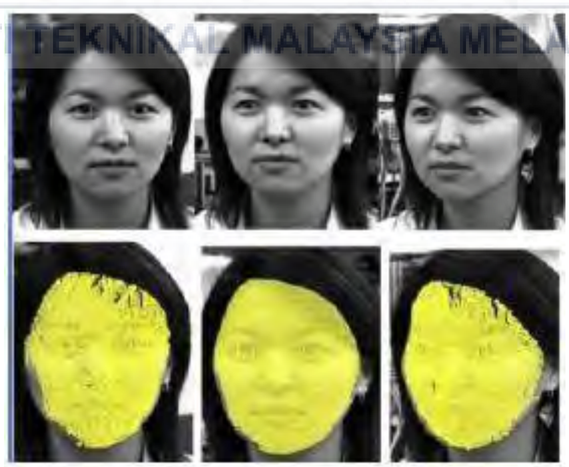

Figure 2.4 Face Scanning Process by Using Multi-image Process.

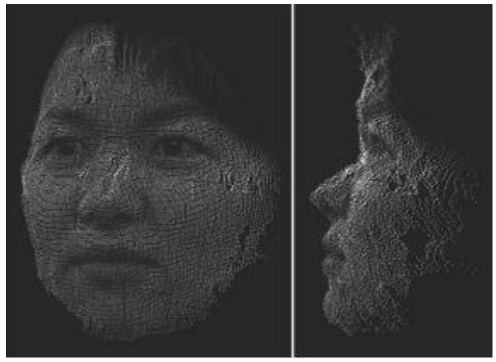

Figure 2.5 Resulting 3D Point Cloud.

2.4 MICROSOFT KINECT

Kinect is a line motion sensor devices introduced by Microsoft company. Initially, this invention is to use with video games for X-box, video game consoles and windows PC's. The introduction of the Kinect camera has open a new impulse for 3D scanners whereby the first distribution of Kinect as 3D whole body scanners was in 2011 and the result shows the system works properly (Daanen & Ter Haar, 2013). In 3D scanning system, this device can be categories as a structural light scanner even though it uses a pattern of near infrared. In early introduction, this device using closed source system software compared to today which the open sources are now available (Daanen & Ter Haar, 2013).

Figure 2.6 Microsoft Kinect for Xbox 360.

The Kinect (Figure 2.6) contains an infrared (IR) emitter and IR depth sensor (640 X 480 pixels) for 3D tracking, a RGB camera with (1280 X 960 pixels) and microphone array (Verdonschot et al, 2015). This microphone array consists of four microphones for capturing sound. The infrared emitter works to emits infrared light in “speckle pattern” which the dot of the infrared lights fall in front of the Kinect camera. These patterns later will received by IR depth sensor and the depth of an object will be determined by looking the displacement of the specific dot of pattern. This pattern produce is a near-infrared which is cannot be seen by human eyes (Daanen & Ter Haar, 2013).

In 3D scanning system, this technique offers low price and it can works under difficult light conditions. However, this device has limitations and can be used with only certain size of object as the depth map resolution of the Kinect is only up to 640 X 480 pixels. Apart from that, this Kinect sensor basically can capture depth and color image data simultaneously at a frame rate of 360 fps, which the data obtained will procedure averagely 300 000 points of colored point cloud in every frame (Kourush & Sander, 2012). In measuring the depth of on object, a triangulation process is applied where the angle and distance between images and the projected light source (laser or LED) produce the base of triangle. Once the triangle complete which the angle of projected light reflect back to the imager from the surface, the 3D coordinate can be obtained and calculated.

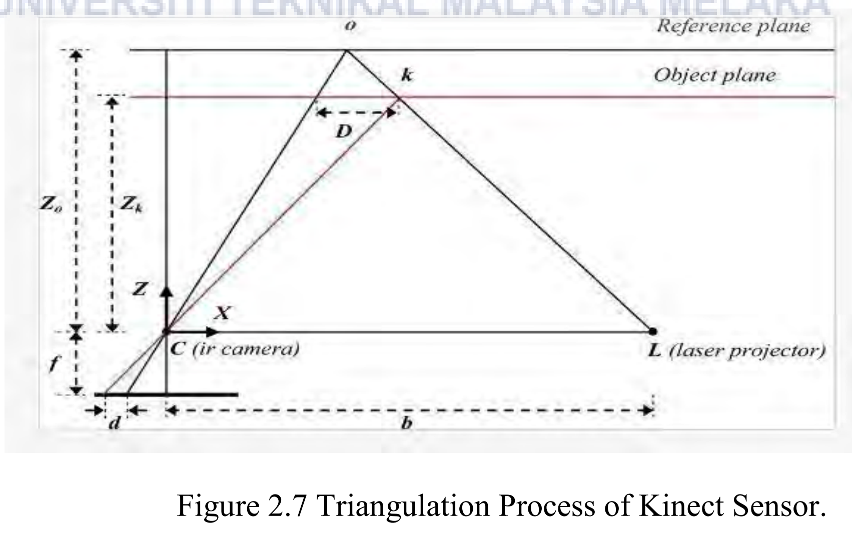

Figure 2.7 Triangulation Process of Kinect Sensor.

The depth accuracy and resolution of Kinect data are effect by certain factor such as the sensor, measurement setup and the properties of the object surface (Kourush & Sander, 2012). The sensor factor may be cause from the inaccurate measurement and inadequate calibration during the experimental process. Thus, an error in estimation of the calibration parameters lead to the systematic error in determining the object coordinates of the individual points. In term of the measurement setup, the error may due to the lighting conditions and the imaging geometry. The correlation and measurement were influence by the lighting conditions because with the present of the strong lighting, the speckles pattern tends to appear in low contrast in infrared images. As a result, a gap is present in the resulting point cloud. For this reason, the imaging geometry is crucial whereby this imaging geometry is includes the distance of object and the orientation of the object surface relatively to the sensor. The present of gaps will result some parts of scene be occluded and shadowed.

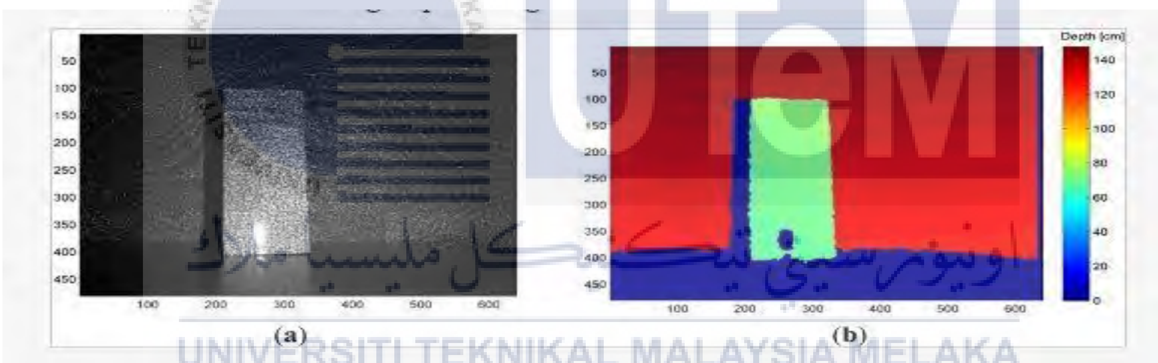

Figure 2.8 (a) Infrared image of speckles pattern (b) Depth image result

From figure above (Figure 2.8 (a), the object is occluded as it cannot be seen by the IR camera even it undergoes illuminated by the laser pattern. The depth image is obtained (Figure 2.8 (b)), however the result is not adequate. Thus, the properties of the object surface also play an important role in measure the points. As can be seen in figure 2.8 (a) smooth and shiny surfaces are appearing in the IR image (Kourush & Sander, 2012). In order to improve the accuracy of the depth of the image data, reflective objects such as metals, it is advised to coat the surface with an acrylic primer (Galantucci et al 2015).

2.5 POINT CLOUD

Point cloud is a set of data points in a given coordinate system. Basically, in 3 dimensional coordinate system, this point cloud is reviews in x, y and z directions and used to represent the external surface of an object. This point clouds can be produced by using 3D scanners. In 3D scanning system, this point cloud is considered as a data structure which will be used to represent a group of multidimensional point on the surface of an object (Weinmann, 2016). After all the point is obtained, the CAD model is reconstructed in STL file.

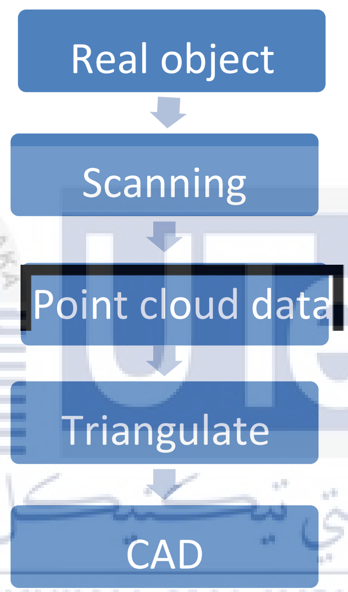

Figure 2.9 Flowchart of Methodology of 3D Scanning Process

This 3D point clouds contains very important shape and some information which allows to model context and spatial relationships between object (Liu et al, 2014). The information obtained from the point cloud will be used in triangulation process. The triangulation process will produce triangulation algorithm and this triangulation algorithm will be used to convert point clouds data into a triangular mesh (Sitnik & Karaszewski, 2008). In order to obtained overall image of the object, it is necessary to measure from several directions depending on it geometry complexity. Since the existing triangulation algorithm data obtained from the optical measurement systems such as structural light and laser triangulation, is not accurate and unsatisfying, a new triangulation algorithm was develop. Sitnik & Karaszewski (2008) have developed a new triangulation algoritm which is known as Mesh3D where the main purposed of this algorithm is to enable automatical processing of 3D scanned data to gain full automatic real objects' digitization process. Using this Mesh3D triangulation algorithm, the point clouds used were divided into several stages. They are detection of sharp edge area, seed triangle on the entire point cloud and lastly, the triangulation of the remaining area. To implement and testing this algorithm, a point clouds from various real object measurement is used (refer table 2.1)

Table 2.1 Descriptions of the Object's Measurement (Sitnik & Karaszewski, 2008).

Object	Features
Skull	Biological object, no edges, high measurement noise, no surface reflection.
Bone	Biological object, simply surface, no holes, low measurement noise
Sculpture of Dog	Several sharp edges, high measurement noise
Sculpture of Human Head	No sharp edges, low measurement noise, point cloud merged from several directional point clouds.
Metal Element	Technological object, very high measurement noise, refraction and reflection, sharp edges, several planes
Plough	Historic exhibit, very complex, partially made from wood and metal, reflections, sharp edges
Gargoyle	Several sharp edges, partially reflective, very complicated shape

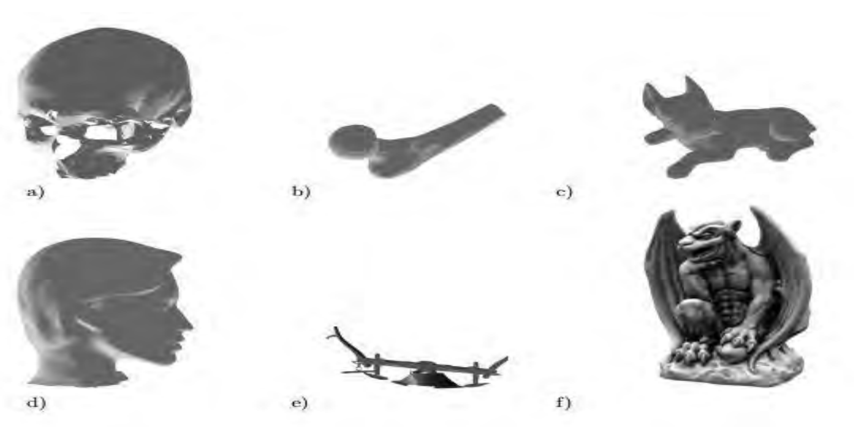

Figure 2.10 Meshes created by using Mesh3D triangulation algorithm.

Zainuddin et al.(2009) introduced a data reduction procedure test by using a laser point cloud. A filter noise is proposed by applying statistical method to removed unwanted point but at the same time, remain the measured featured. Besides, the filter redundancy approach is used during the pre-processing using sampling method. This sampling method used to reduce the amount of point cloud to make the data well structured. Different from this filter redundancy process, which works to removes the amount of point cloud on data surface whenever the point overlapped to each other. Thus, this step can be applied in laser scanner data to reduce the input redundancy and certain amount of error introduced due to the limitations of scanner.

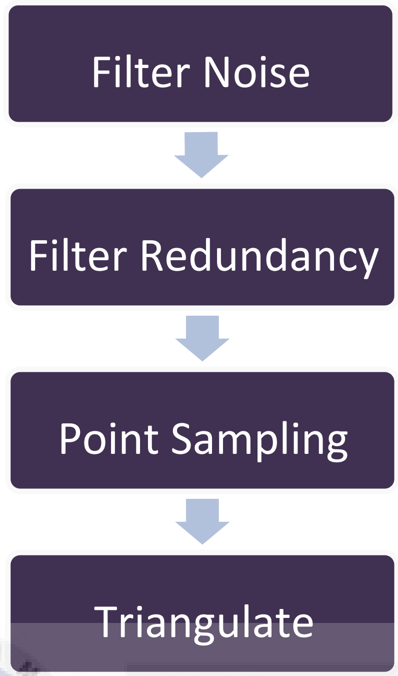

Figure 2.11 Flow Chart Process of Data Reduction Process.

2.6 IMAGE PROCESSING

Image processing is the preliminary process during the entire scanning process. This process is a pre-stage step in determine and analyze of a digitized image, especially in order to improve its quality. This image processing includes image filtering, noise removal, geometric image transformation, feature points detection and etc. In 3D scanning system, this image processing is focuses on intensity of image (Manor & Fischer, 2001). According to Manor & Fischer (2001), there are many ways for directly obtaining a digital image of light intensity such as solid devices. The intensity of the formation of image can be classified as two parts which are the geometry of the formation of image and the physics of light. The geometry of the formation of image determines the where the projection of the points in the scene should be located on the plane’s image. Meanwhile, the physics of light will determined the scene of illumination and the surface’s properties. During the image processing occurs, the noise removal is important and most of this process will do the prep stage. To simplify, this image processing is a process after all point cloud is obtained, the point cloud transfer to triangulate phase and mesh to CAD surface.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, all the methodology used was discussed. The first phase describes on how the brainstorming process occurs until the design comes out with the conceptual design and design specification. Next, for the second phase will discussed on the development phase which including the morphological chart. As the result, the concept design comes out with a final conceptual design with complete engineering design characteristics. After all, a 3D drawing of the final product is drawn by using computer software.

3.2 PROCESS FLOW CHART

In an engineering design, problem statement is the important step for development of product. In this stage, the formulation of the problem should start with listing down all the problem statement. This document should include all the objectives and goals, desired state and even any possible solutions for the problem stated. Next, a preliminary stage is applied which during this stage some background research is required, making concept design and design specification, drawing morphological chart and lastly include the engineering design. During this stage, a literature review on articles, books, journals and etc is required to gathering all the information needed. In the same time, during this phase the conceptual design is produced and expressed by using a diagram block table. The design specification is made to provide detail document about the characteristic that the product should have and to set the criteria that the product should meet. The next step is proceeding with morphological chart. This morphological chart is used to generate all designs by synthesizing all the possible combinations of alternatives based on each sub-function solutions. After the preliminary design, the process proceed with detail design process involving material selection, manufacturing process, detail drawing. At last, the fabrication is made based on the final conceptual design. The sequence of the process of the development product is illustrated as the flowchart below.

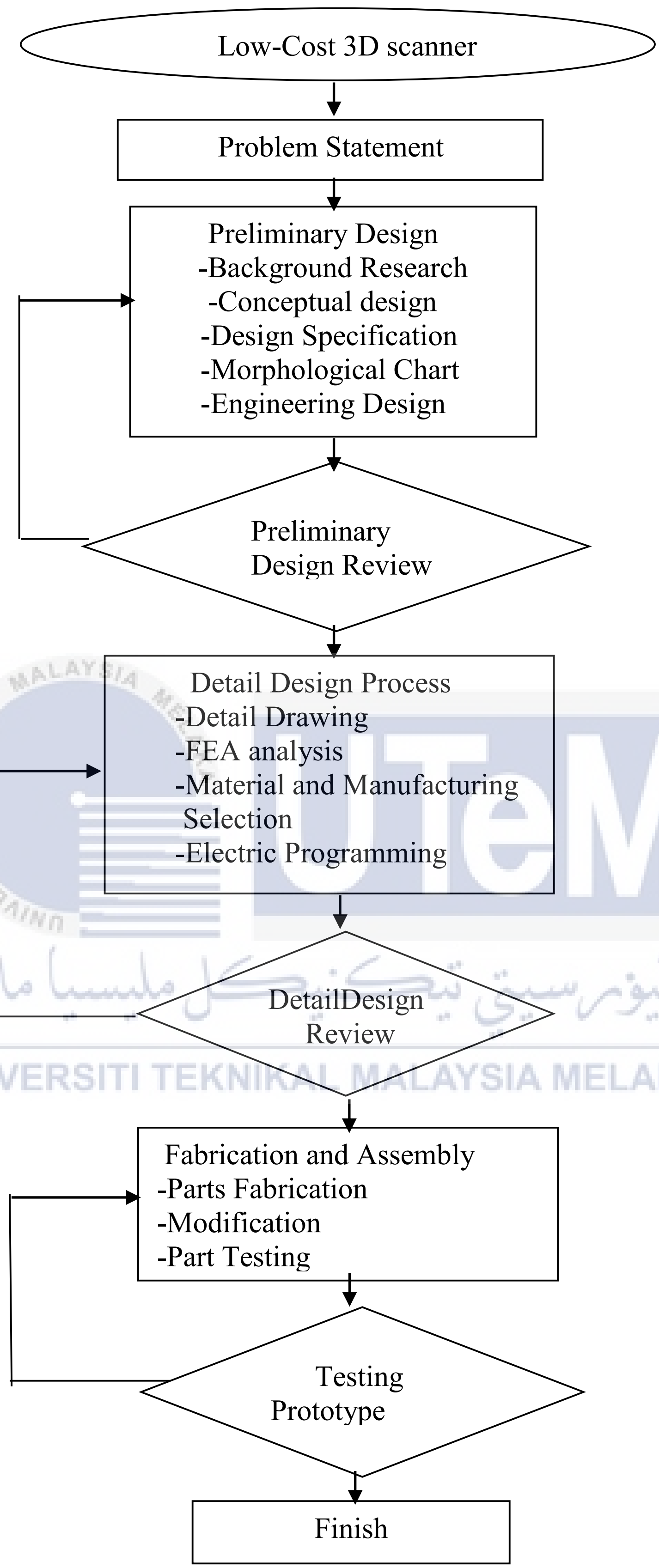

Figure 3.1 Process Flow chart for Development Product.

3.3 CONCEPTUAL DESIGN

Conceptual design is a preliminary design in deciding the shape, material, design function and etc. During this stages, the concept of design is generates which includes a broad set of concepts that have will satisfy and potential to solve the problem statement. The conceptual phase focuses on the problems and comes out with new ideas or solutions to the previous problems. A brainstorming is needed to produce creative methods to produce sets of concept design. The importance key in concept generation is by combining the creative idea from the brainstorming process and all the gathered information.

At this stage, a product design specification (PDS) planning is design to search and identify all the specification and how the requirements are to be met. In this PDS table, all the requirement are listed to guide and describe how the product that is intended to be produced. In order to generate new concept of low cost 3D scanner, thus the design will focuses on few aspects which are cost, performance, installation, safety and lastly the material to be used.

Table 3.1. Product design specification.

No	Criteria	Description
1	Cost	Low cost
2	Performance	Easy to handle Easy to maintained
3	Installation	Easy to installed using simple tools
4	Safety	Does not have any sharp corners Does not harm user
5	Material	Anti- rust Light weight Strong

3.4 MORPHOLOGICAL CHART

Morphological method is a method to analyze and represent the relationship in multidimensional problems. This method is one of the techniques to generate designs solutions. This morphological word is come with meaning which is to study shape and form. Morphological chart is a chart which contains several of set components in each problem. This chart is used to help simplify the problems by synthesis different component to fulfill the desired function. Basically, in morphological approach to design can be divided into three ways. Firstly, identifying the overall design problems and dividing it into each sub problems. Next, generate the solutions concept for each sup problems. The solution concepts of each sup problems will the systematically combine together to produce into different complete solutions. Lastly, these different complete solutions will be evaluated.

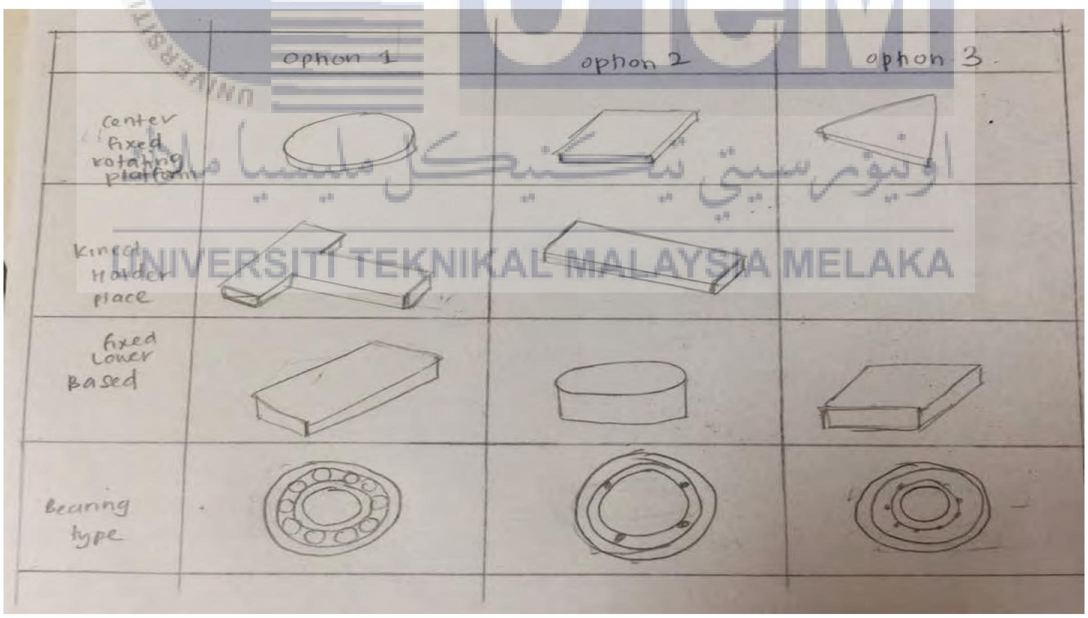

Figure 3.2 Morphological Chart of the rotating platform.

In morphological chart, one possible design concept is obtained by combining the entire alternatives component in the first row under each sub function by referring to the previous PDS table. At this stage, the option was set into 3 which contain of each sub component. These sub component are consist of center fixed rotating platform, Kinect holder place, fixed lower based and bearing type. By combining all this sub problem component at random selection from each column will creates another possible design and each design that obtained from this method need to be checked for feasibility. As a result, all this 3 possible design were known as new design concept which all the combinations will be evaluate to choose the best design. By using this method, it allows the designer to explore many alternatives design solutions.

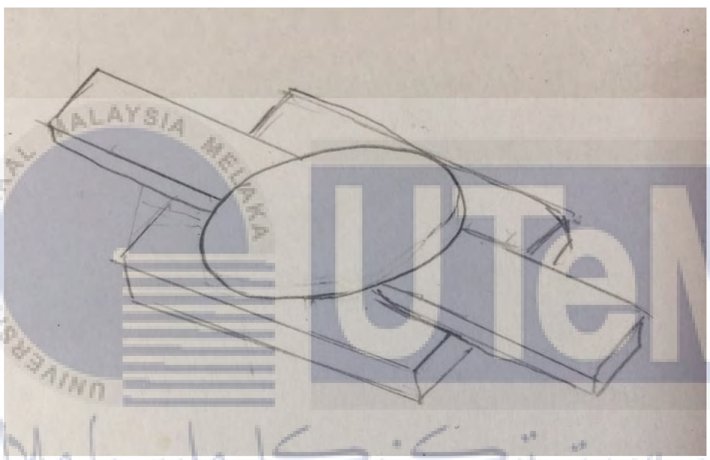

Figure 3.3 Design 1 of combining each component sub alternatives component.

Design 1 consist of the round center fixed rotating platform and square fixed lower based. This round center of fixed rotating platforms area is wider compared to the other design and in term of stability, this design gives the best stability since the based is in square shape.

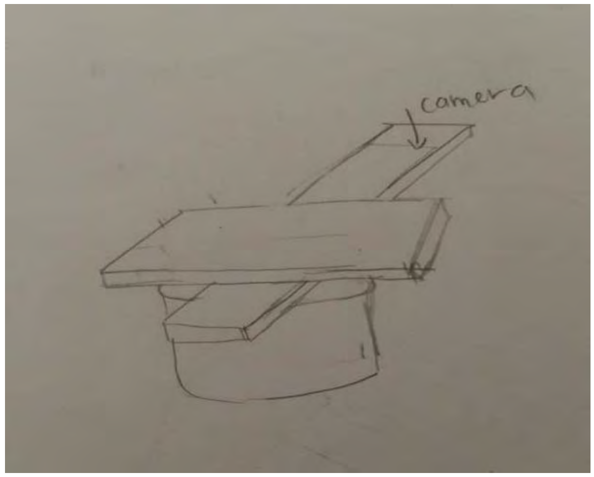

Figure 3.4 Design 2 of combining each component sub alternatives component.

Design 2 consist of a rectangular fixed rotating platform and a circular base. This base is slightly higher compared to other design and the rectangular platform will constraint the object that will be placed onto it.

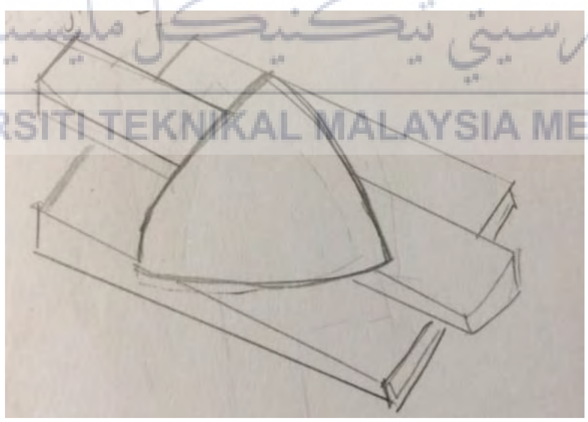

Figure 3.5 Design 3 of combining each component sub alternatives component.

For design 3, the base is rectangular and the platform is in triangular shape. This triangular shape also will encounter the same problem as design concept 2 which will limits the object to be scanned in term of its size.

From this morphological chart, 3 design concept is obtained (refer Figure 3.3, 3.4 and 3.5).This 3 designs is basically consist of rotating base which will be used to moves the Kinect sensor around the static object where the objects is placed at the center of the fixed platform. Each design is varies and has different shape to obtained best alternative in this research. In this design, an approach of using rotating Kinect by using hand will be used since distance between frame object and its sensor itself and most importantly the ability and quality of the measurement from this sensor can be analyze and conclude from the data of its accuracy and precision itself. Since the IR camera and IR projector is short which is probably in 0.074m thus minimum distance from the sensor is necessary for the depth acquisition.

In order to evaluate all this conceptual design to obtain the best design, a Pugh chart is tabulated. This Pugh chart is a method that compares each concepts which related to a reference or datum concept to determines whether the object is better or poorer than or same as the reference concept.

Table 3.2 Pugh concept selection process.

Criteria	Smart 3D Pixelio	Design		
		1	2	3
Platform area	D	S	-	-
Weight	A	-	-	-
Cost	T	+	+	+
Stability	U	+	-	-
#pluses	M	2	1	1
#minuses		1	3	3

From morphological chart, a 3 conceptual design is generated for rotating platform of the 3D scanner. The Pugh concept selection process (table 3.2) were applied to choose the best design based on the reference criteria. A smart 3D Pixelio was set as a datum which will be used as a reference concept which all other concept are compared. By referring at table 3.2, all the proposed concepts offer the improvements at the cost aspect. In term of weight aspect criteria, all 3 concept were failed to meet the level performance of the datum. In this table, design concept 1 has the highest value of pluses compared to the others design. This concept has the same criteria as the datum, and shows the improvement at cost and stability aspects. Thus by referring all this criteria, this design concept can be considered as the best concept design.

3.5 DETAIL DESIGN

Detail design is considered as the last process of the documentation which includes the detail drawings, the material selection, the description of manufacturing process and etc. A detail design act as a conclusion of the project which used to described the design in detail. In order the design to be complete, it is necessary to test part of the critical component of the final design. This critical component can be tested by using FEA analysis. After the analysis is done, the final conceptual design chosen, the detail drawing is produce by using computer software CATIA. This detail drawing is drawn in three dimensional objects which complete with dimensions and tolerances. Next, from this drawing, an analysis is done to measure its maximum and minimum critical value of the structure by using FEA analysis.

In engineering design, finite element analysis (FEA) is important for predicting the behavior of the element on how it react to the given pressure, force, vibration, heat, fluid flow and etc. This FEA is a computerized method by using computer aided system (CAD) software like CATIA and SOLIDWORKS where this analysis will compute all the force and pressure given to show whether the product will break, worn out or work as the way it designed. In this experiment, all the product part are analysis to obtain the related result.

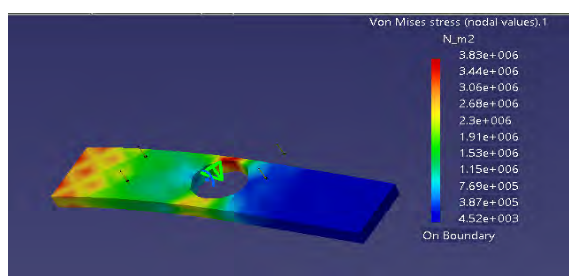

Figure 3.6 (a) Rotating Platform (b) FEA of Rotating Platform.

Figure 3.6 (a) shows a CAD drawing of rotating platform where the material used is wood. This part is undergoes FEA analysis to shows strengthens towards the given force. This rotating platform will be used to hold the Kinect Xbox sensor and will rotate in circular motion. A 50 N force is applied to the top of this platform to calculate the displacement and the von misses stress. As the result from FEA (Figure 3.6(b)), the maximum von misses stress is 3.8e6 Pa and this value is used to predict the yielding of material any loading condition. Simply put, this von misses is calculated by the designer to ensure that the whether their design can withstand a given load. The material is said to be yielding if the von misses value is exceed the value of the material strength. In this case, the yield value of material from the rotating platform is lower than the von misses stress, thus it can be said that this design is safe.

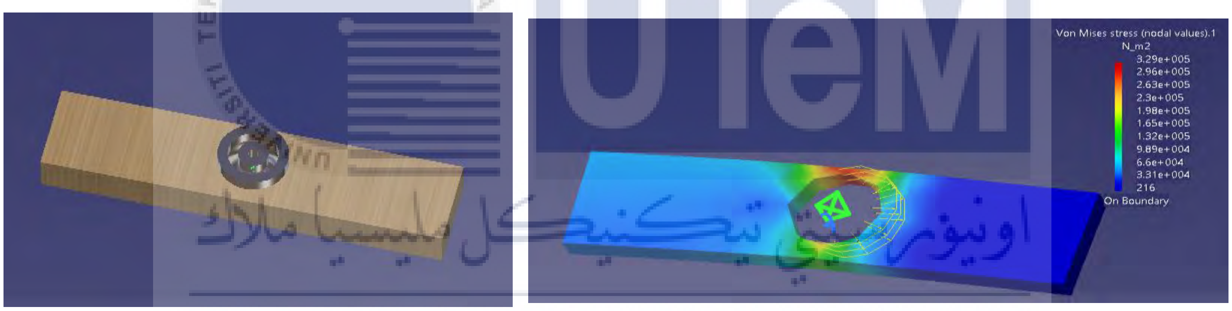

Figure 3.7 (a) Rotating Platform connected with bearing (b) FEA analysis result.

The presence of the bearing (Figure 3.7 (a)) will cause a bearing stress on the contact area. Thus, an analysis is made to calculate the maximum von misses and the strength of the material. From the FEA analysis (Figure 3.7(b)), the maximum value of von misses is focuses on the bearing area with 3.3Mpa.

3.6 MANUFACTURING PROCESS

In this process, the Kinect holder and rotating plate of platform part will be manufactured by using additive manufacturing of rapid prototyping. A Kossel 3D printer is used to produce the part design by using material used is ABS and PLA plastics. This ABS and PLA plastics is considered suitable as the material selection for this part since the Kinect holder and other part design does not involves in heat source application. The 3D drawing of this part will be transfer into STL file and slicing process will takes place. The part design will be printed layer by layered until final design is obtained. This process is low cost and can be done in short time. Figure 3.8 shows the example of Kossel 3D printer.

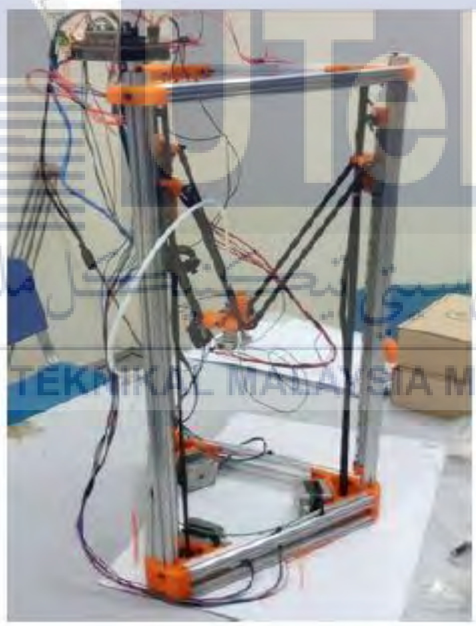

Figure 3.8 Kossel 3D Printer.

CHAPTER 4

RESULT AND DISCUSSION

4.1 DESIGN PROTOTYPE

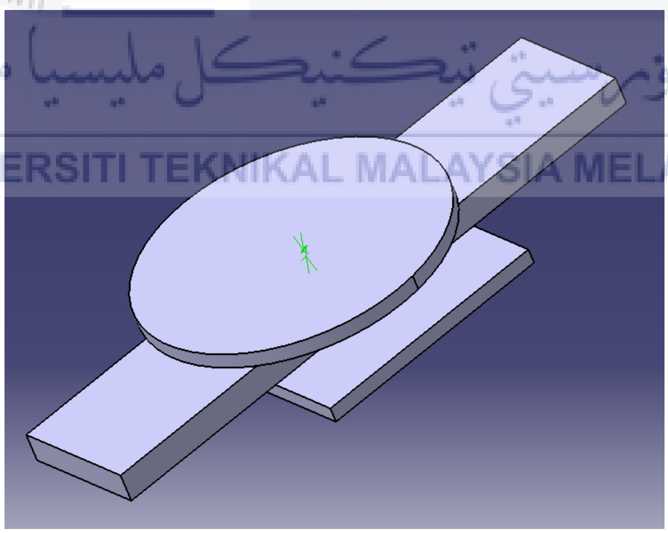

Figure 4.1 Rotating Platform of Kinect Xbox.

Figure 4.1 shows a design prototype where it consists of simple component (table 4.1). This design is using concept of rotating device where the base is used as a support and there is a fixed center to place the object to be scanned. The material for this design is mostly using wood since this is to achieve the objective which is to improve the accuracy of 3D scanner yet in low cost budget. Using this prototype, the Kinect Xbox sensor will be placed on the rotating platform to scan the object by moving in 360 degree of circle motion. On the other hand, the object will be placed on the fixed center platform and will be static during the scanning process. The plain bearing is used as a rotating mechanism and made from aluminum.

Table 4.1 List component of rotating platform with fixed center.

Component	Material
Fixed center platform	Plastic
Plain bearing	Aluminum
Rotating platform	Wood
Base	Wood

4.2 CENTRIFUGAL FORCE

The platform is used to place the Kinect Sensor Xbox to capture the object data. Some force is applied to this platform to rotate the platform in a full 360 degree circle. Thus, centrifugal force is acting on this platform since this force is applied on a rotating devices (please refer figure 4.2). This rotating force is an inertial force which directed away from axis of rotation that appears to act on all objects when viewed from rotating frame. The centrifugal force act as the friction which holding the object on the platform and cause the object to move in a curved path. This force is depends on object's mass, rotational speed and distance from center of curvature. The greater the speed of rotation will lead to the greater outward force produced.

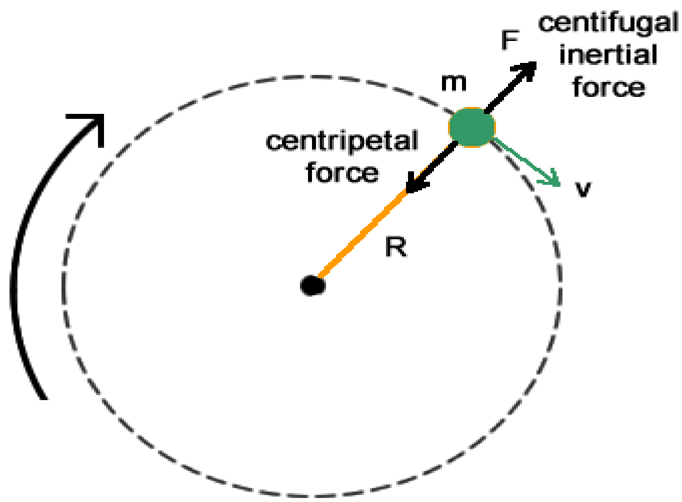

Figure 4.2 Illustration of Centrifugal Force.

Centrifugal Force:

$$F = mv^2 / R \quad (1)$$

Where F is the force that pulling the object away from the center, m is mass of the object, v is the straight line velocity of the object meanwhile R is the radius of curvature caused by the centrifugal force.

4.3 BEARING DESIGN

In this design, bearing (Figure 4.3) is used as a rotation mechanism since bearing is a device that enable rotational and linear movement while reducing friction and stress. It is crucial in choosing a right bearing design since in order to prove the design is safe, it is need to considered several factors that will affect the wear and the service life of the plain bearings. One of the several factors are including specific bearing load, sliding speed, surface roughness, PV value and operating temperature. In this experiment, the specific bearing load is used in Spherical Plain Bearings to calculate the allowable applied load.

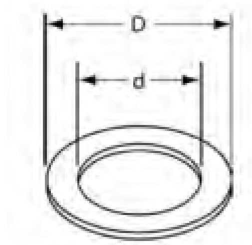

Figure 4.3 Bearing Schematic.

Specific Bearing Load (N/mm^2):

$$P = \frac{4W}{\pi(D^2 * d^2)} \qquad (2)$$

Sliding Speed (m/s):

$$V = \frac{\pi . D . N}{60.10^3} \qquad (3)$$

Table 4.2: Formula

P	Specific bearing load	N/mm^2
D	Outside diameter	mm
d	Outside diameter	mm
W	Load on the bearing	N
N	Speed of rotation	rpm

From the presence of sliding speed, the friction force is produce and this will affect the wear rate of the bearing. Simply put, this calculation, it can calculate the bearing life to expect how this bearing can operates under the given load. It is crucial to know the bearing life so it can be replaced right before this bearing is wear and cannot be used.

Bearing life hours:

$$L_{10} = \left(\frac{10^6}{60n}\right) * \left(\frac{Cr}{\mathrm{Pr}}\right)^3 \qquad (4)$$

Where:

L_{10}= Hours (h)

Cr= Basic dynamic radial load rating (N)

Pr= Dynamic equivalent radial load (N)

n= Speed (rpm)

4.4 EXPERIMENT SET UP

A model of platform with a fixed center was design (Figure 4.1). The object is placed at the fixed center and scanned by using the moving Kinect Xbox 360. By using hand manually to moves the Kinect sensor, the Kinect sensor will moves continuously in circular motion to capture around the image of an object in 360 degree viewpoints. Skanect scanning software is used as the medium to process the image until it form 3D scanned model. This 3D scanned model then will be convert into STL file format where this file can be imported into a CAD software by using Solidworks to take the measurement. In this experiment 3 object is taken to measure the accuracy of the Kinect sensor towards the scanned object to be compared to the measurement taken manually by hand.

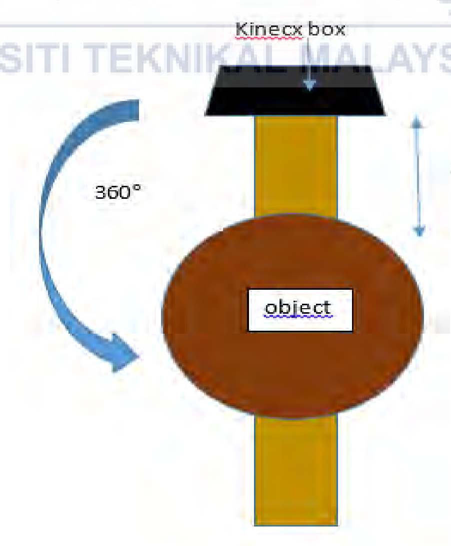

Figure 4.4 Experimental Setup.

4.5 RESULT

4.5.1 COLOR ACCURACY

As for result, Skanect software is the medium used to capture the motion of the object. This software will capture full color of 3D model of an object, room or a body of a person with just simple steps and affordable price. This software will transform the Kinect Xbox sensor camera into a low cost 3D scanner and will create 3D meshes out of real scenes in just a short time duration. An experiment was carried out by scanning a different type of object by using this software to compare the accuracy between the real object and the scanned objects.

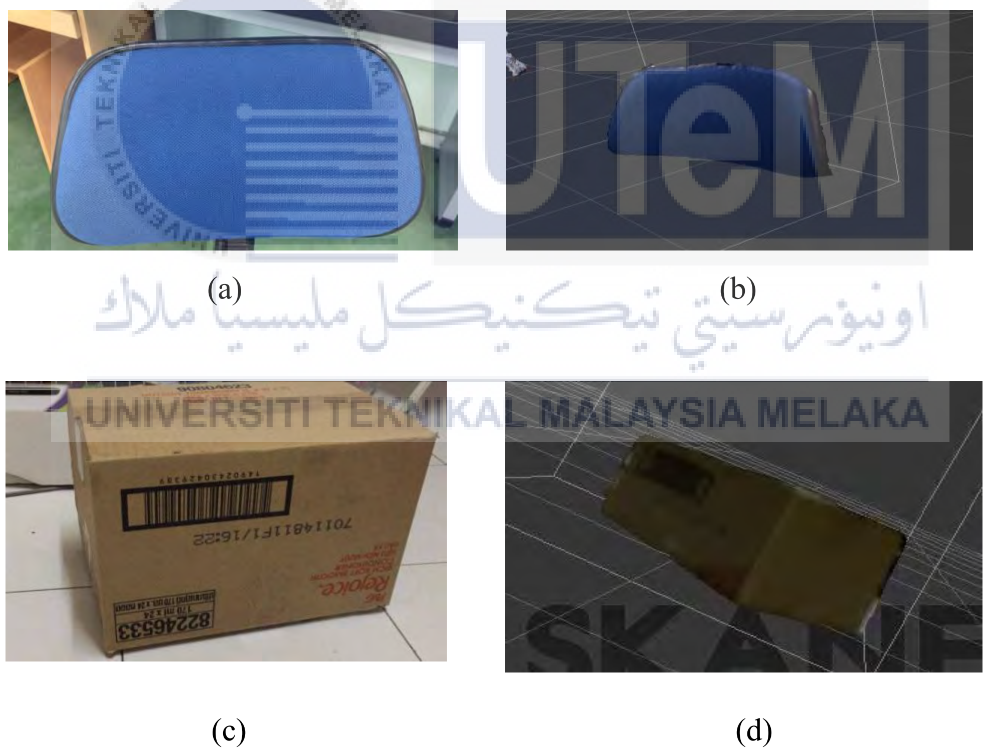

Figure 4.5.Experimental Result. (a) Real chair. (b) Virtual 3D scanned chair. (c) Real box. (d) Virtual 3D scanned box.

From the result (Figure 4.5 (a), (b), (c) and (d)), shows that this Skanect software is able to captured the object with full color. The virtual 3D data object produce by using this software are similar with the scene frame of an object.

4.5.2 DIMENSION ACCURACY

Kinect IR image and depth were analyzed in order to evaluate the accuracy and precision of the Kinect sensor by using different objects as the data. An experiment was carried out by capturing 2 to 3 different objects with different geometry and surface which captured by this sensor. The objects were statically stand at the fixed center of platform (Figure 4.4) and the Kinect sensor will rotates to captured frames and rotate up to 15 fps. As a result, single 3D model then will be construct from the relative position between the sensor and object during the continuously scanning process. The data obtained then will be analyze to obtain the quality of the measurement. This quality of measurement refers to the accuracy of the dimension of actual object is taken to be compared with the data obtained from the scanning process. The virtual 3D object produce by the Skanect which is in STL file will be converted into CAD file by using Solidworks software. This Solidworks will add inn 3D scan object into CAD file which will produce the mesh file and dimension which then will be compared with the real object. This comparison data is calculated to obtain the percentage difference.

(a)

(b)

(c)

(d)

Figure 4.6(a). Real shoes box. (b). 3D shoes box in CAD file.
(c). Real cup. (d). 3D cup in CAD file.

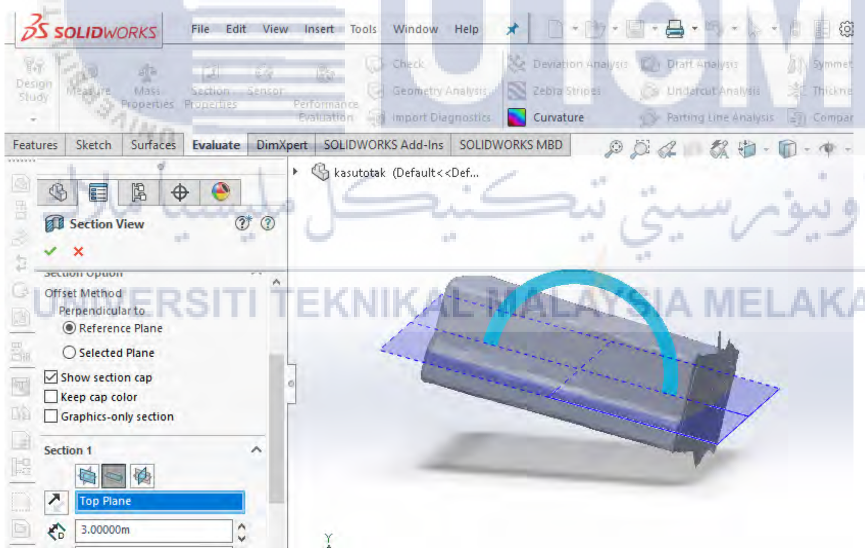

Figure 4.7 Process to measure the dimension of 3D virtual shoes box.

Table 4.3: Data of Object.

Object	Scanning Dimension (cm)
Chair	30 x 19
Box	35x22
Shoes Box	30 x 9.8
Sport Shoe	30
Cup	Ø11.6

Where the formula for percentage difference is:

$$\% = \frac{|Approximate\ value - Exact\ value|}{|Exact\ value|} \times 100 \quad (5)$$

Table 4.4: Percentage Error of Object (Horizontal Length in cm)

Object	Exact	Approximation	Percentage Error%
Chair	32.0	30.0	6.25
Box	35.0	33.2	5.1
Shoes Box	30.5	30.0	1.6
Sport Shoe	30.0	27.4	8.6
Cup	11.6	11.0	5.1

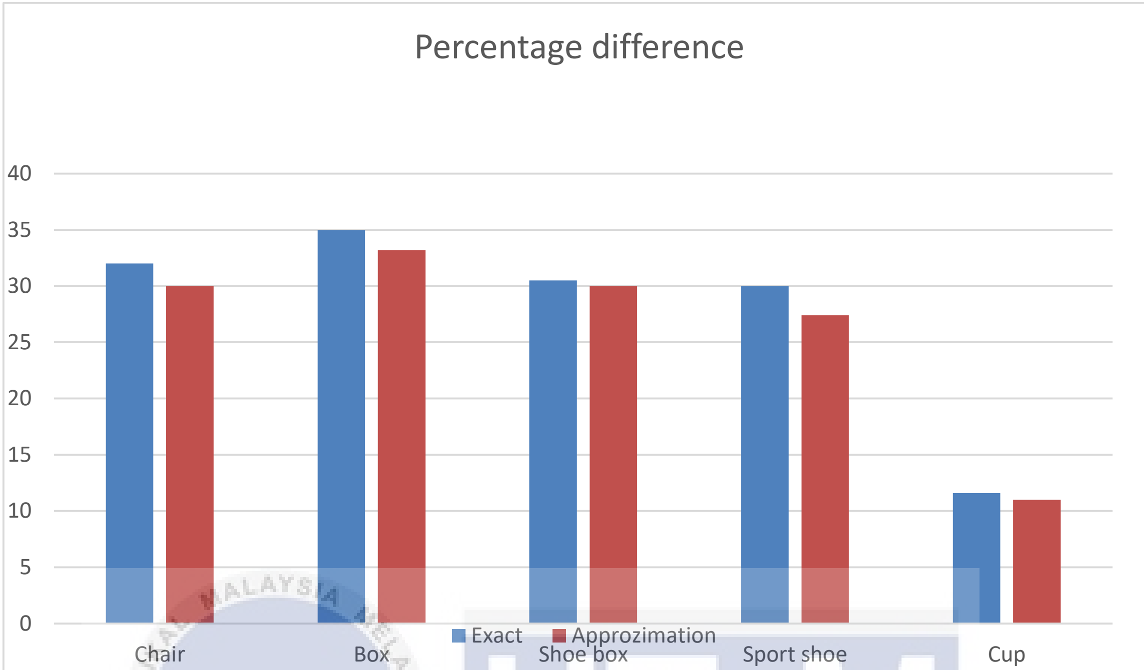

Figure 4.8. Graph of percentage difference of each data.

4.6 DESIGN OF EXPERIMENT (DOE).

Apart from the experimental setup, the design of experiment is conducted which applying statistics to experimentation. This approach is used to develop a mathematical model which will be used to predict on how all the possible related variables (factor) are interact with each other to produce an output variable (response) in a system. This approach is to achieve the objectives which the data will be used as verification and thus, the conclusion can be made. In this experiment, 2x2 factorial design is set which the speed and the surface object is set as the factors to investigate the response of the ability of height object captured during the scanning process. A factorial table (Table 4.5) is tabulated in order to ensure all the possible combination of factors level are tested.

Table 4.5 Factorial design factor of two-interaction.

StdOrder	Run order	Speed	Surface Object	Response
4	1	-1	1	11.0
3	2	1	-1	27.4
2	3	-1	1	30.0
1	4	1	-1	33.2

Where:

Table 4.6 Indicator of factor.

Speed	Surface object
-1 = Low speed (<10 FPS)	-1 = Smooth
1= High speed (>15 FPS)	1= Textured

In order to run and analyzed this data from experiment, a Minitab software is used by using stat of design of experiment (DOE). All this factorial data is transferred into factorial plot to obtain the graph of mean effect plots for height object and the interaction plot.

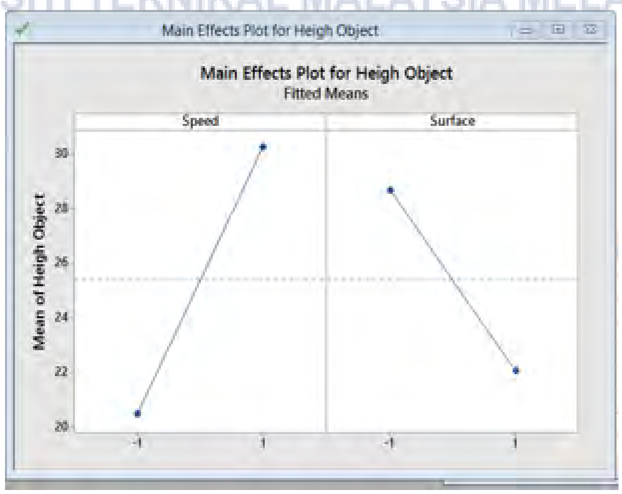

Figure 4.9 Main effect plot for response.

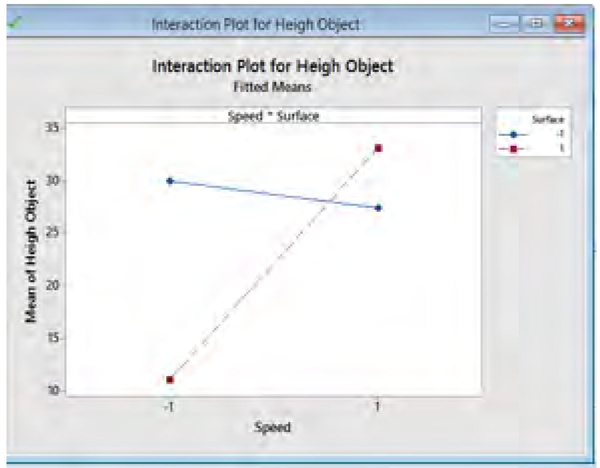

Figure 4.10 Interaction plot.

As the Figure 4.9 shows, the speed does effect the response where the higher speed, the higher the ability of the scanner to captured the height of an object. As for the surface of object, the accuracy to capture the height data is high compared to the textured object. The interaction plot (Figure 4.10) shows there is an interaction between this 2 factors since the line is not parallel. From this graph, the smooth object obtained high mean value of response when the speed of the sensor is slow compared to result when using high speed. Meanwhile, the textured object will have low mean height value if the speed is low and vice versa.

4.7 DISCUSSION

Kinect Xbox 360 is a low cost of an active camera which created for gaming purposes. Since this Kinect Xbox 360 is for gaming activity, it is necessary to investigate the accuracy and precision of its sensor. The accuracy and precision of this sensor is basically related to distance between frame object and its sensor itself and most importantly the ability and quality of the measurement from this sensor can be analyze and conclude from the data of its accuracy and precision itself. In this experiment, a different type of real object data were taken in order to analyze the accuracy. For each data of each object, an exact value and approximate (from the 3D scanner) value were taken to calculate its percentage difference. This percentage difference is taken into account in order to define possible systematic error which can be corrected later by calibration procedure. From the result data (Table 4.4), the highest percentage error obtained is 8.6% and the lowest percentage is 1.6%. All the percentage difference were quite high and difference according to its surface which shows that the accuracy is low.

Figure 4.11. Mesh of sport shoe.

From Figure 4.11, the image delivered by the sensor is lack and contain some missing information. From the result, it can be conclude that structured light of the sensor does not reflect and robust enough towards the frame scene. This may be cause by specification of the sensor itself which it can only collect data in range of 0.8m to 4.0 m since the IR camera and IR projector is short which is probably in 0.074m and the type of the object itself. In order to overcome this, a minimum distance from the sensor is necessary for the depth acquisition. This can be achieved by improves the experimental set up by avoiding any bright light sources from windows and this can be achieved by placing the object towards wall during the scanning process while moving the Kinect moving around it.

By referring to the design of experiment, the surface of object does effects the accuracy of the Kinect as 3D scanner. The smooth objects are usually have reflectiveness where this reflectiveness is hard to be projected by the sensor to calculate its depth acquisition. Thus, in order to overcome and improves this problems, the smooth object can be fully coated by using by applying white color coating spray which to reduce the reflectiveness of an object to be scan and during the 3d rendering, it is advisable to used low frame rate per second to ensure all the surface is detected by the 3d scanner.

CHAPTER 5

CONCLUSION

Kinect Xbox 360 is an active camera which use structural light in triangulation way in range of 0.8- 4.0 meter. With the present of the open source such as Microsoft SDK driver, Skanect software and others open sources software has changed the main purposes of this Kinect sensor from gaming devices into measuring devices. This Kinect sensor are able to be used as 3D scanner for measuring purposes and even for prototyping purposes by collecting the 3D data which then can be directly printed by 3D printer. By using this Kinect sensor as a low cost 3D scanner, it is necessary to analyze and calculate the accuracy of the frame scene obtained. The accuracy is varies depends on the distance between frame object and the sensor itself. As mention earlier, it is important to analyze and calculate the accuracy as to correct all the possible systematic errors during the calibration process. From the experimental result, this Kinect sensor mostly are able to captured and delivered data up to 60% where the data is obtained by moving the Kinect sensor around the static object. This technique of moving the Kinect instead of the object is quite interesting and the value is quite acceptable as the percentage difference is less than 20%. To simply said, the present of the open source software and hardware, this Kinect Xbox 360 sensor is able to be used as low cost 3D scanner and by implement the technique of moving sensor can reduce the percentage difference which can make the values near to accurate.

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