

3D OBJECT ACQUISITION SYSTEM

by

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CERTIFICATION OF APPROVAL

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD RAHISHAN BIN RAMLEE

ABSTRACT

This paper present the study on the investigation of the procedures to obtain 3 dimension (3D) acquisition system. The processes start by determining the best pattern to be used in obtaining the best deformation pattern image. Three pattern being projected on the the test object to see the pattern deformation. Pattern which give clear and vivid image when capture by the camera will be selected. Vivid deformation pattern will be used for further analyze by using the software. For software related, the deformation pattern that being choose to analyze will give the data coordinates of the test object. Based on the data obtained, the 3D system of the test data can be acquire. With the data coordinates also, polynomial equation algorithm can be generated to acquire the polynomial equation related with pixel coordinates depth corresponding with the real world depth. This paper will present the investigation in choosing the best projected pattern to be implemented in obtaining the 3D system as well as the image acquisition and analysis using MATLAB to produce desired equation.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The rapid growth of 3-Dimension (3D) software and hardware for computer visualization and 3D scanning technologies made feasible the acquisition and reconstruction of complex surfaces in many fields [1] such as clothing manufacturing, 3D scanning technology, medical science and many more. Other than that, according to [2] face reconstruction is the preparative foundation of such relative researches as face digitalization, face texture, face 3D recognition and face movement. However, for simplicity of this project, it will focus more on finding the location of the simple object coordinates like sphere and cube. This initiative will become basis before proceeding the experiment with the complex objects. But first, the 3D image must be obtained from the testing object before the analysis of the 3D coordinates can be made.

Based on the statement made by [3] there normally exist many methods in detecting 3D location and coordinates, but many of them use a pre-calibrated camera to find the world coordinates. Other method state by [4] including triangulation, stereo-vision and projected fringe technique. Fringe technique method describe by [4] related to projecting pattern on the object surface and the pattern distorted in accordance with the object height. According to [5] the camera calibration will provide way to determine the exact position of the ray lights in a 3D space that the object point must lie on. The same concept apply to this project where the pattern being projected to the testing object using the projector. From the pattern deformed, it being captured by using the camera and the pattern deformed image being analyze by imaging software to produce cloud point thus detecting the coordinates of the object.

1.2 Problem Statement

The problem statement for this 3D object acquisition system project are as follow:

1. How to construct and design experiment to acquire 3D points coordinates of object under test.
2. How to analyze the obtained 3D pattern image using software to represent the data of object under test in coordinates form and thus reconstruct the 3D object.

1.3 Objectives

The objective of this 3D object acquisition system project are as follow:

1. To design and experiment and prototype hardware for a 3D object acquisition system
2. To develop and implement an image processing algorithm to create a 3D point cloud of an object under test and acquired coordinates of each points

1.4 Scope Of Study

The project focus on the field of the intelligent signal and imaging. In this project, the intelligent signal and imaging will only related to 3D construction image and acquisition system. The 3D acquisition system being analyze from the reconstruct of deformed image pattern projected onto the object under test. The deformed pattern image being capture by the camera then being analyze to produce 3D representative of the object.

CHAPTER 2

LITERATURE REVIEW

The 3D technology and coordinate measuring machine were widely used in machine building, precision measuring electronics, automobiles [6]. According to [7] the 3D reconstruction and modeling of objects are the first step in building many application like human-computer interaction, virtual simulation and used in manufacturing section. 3D surface modeling become one the important photogrammetric task which involve many application used such as industrial reverse engineering of manufactured bodies and object recognition [8].

Based on the statement state by [9] good calibration method must be done to get the 3D measurement result with high accuracy and precision. In order to get the 3D measurement, pattern projection analysis were used. Pattern projection will fall into three categories which depends on the coding strategy, time multiplexing and neighborhood codification and direct codification. A sequence of pattern is projected to the surface of the object in time-multiplexing techniques [10]. The advantages of grid line pattern as mentioned by [11] show that grid line always fix to the position where they intersect, posses certain symmetry and most importantly each grid carry information related to position with the local curvatures of the grid lines. Aside from projected pattern, thing such as finding the correspondence between camera and projector are necessary for both calibration and reconstruction of objects [12].

From statements write by [13], the 3D content from scene can be recreated using the “left” and “right” images of an object using the estimation process with the knowledge of the global positioning and orientation of each cameras and correspondences dense between all feature point. The method use by [1] related with two camera that obtained different view of the 2D scan dots on the surface of the object. By using the triangulation procedure, one single 3D coordinates is calculated from the two pairs of the 2D coordinates obtained. Structured light pattern being projected to the

object's surface and the set of projected intensities at each pixels will be decoded for analysis [5].

The method propose by [14] relates to the structured-light method which is divided into single-structure light, linear structured light and encoded structured light. The 3D information of the object could be acquired by only one image captured by the camera. However, because of the camera's view was limited or the surface of the object was covered, the whole information of surface cannot be recovered. Hence, the object being measured in different angles or different regions to get the required data.

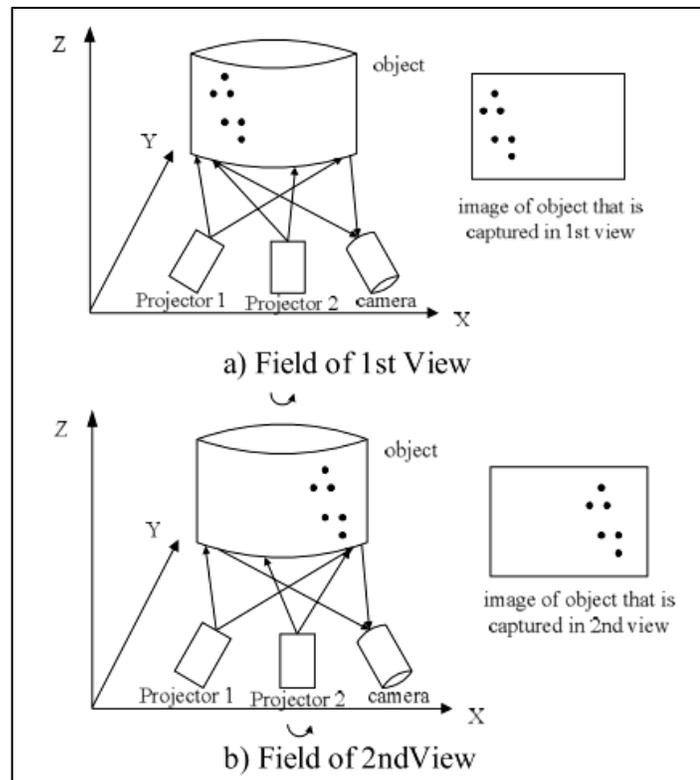


Figure 1 : The measurement system (Source taken from literature [14])

There are standardization process in high level acquisition and modeling of 3D object that can be used as guidance. The system being proposed by [15] related with three main components that start with view acquisition, view registration and surface reconstruction model. In addition to [15], the view acquisition involve in capturing views of object in different angle and viewpoints. These accumulated views then being transformed to object centered-coordinated system before the surface can be obtained.

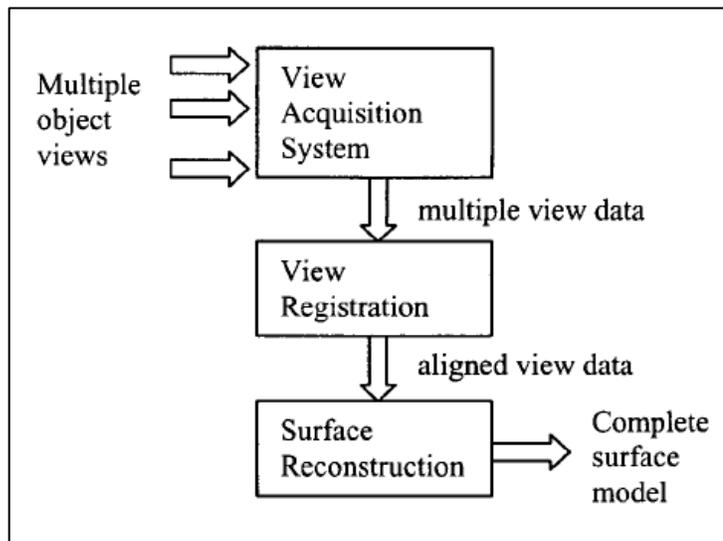


Figure 2 : Acquisition and Modeling System (Source taken from literature [15])

CHAPTER 3 METHODOLOGY

3.1 Research Methodology

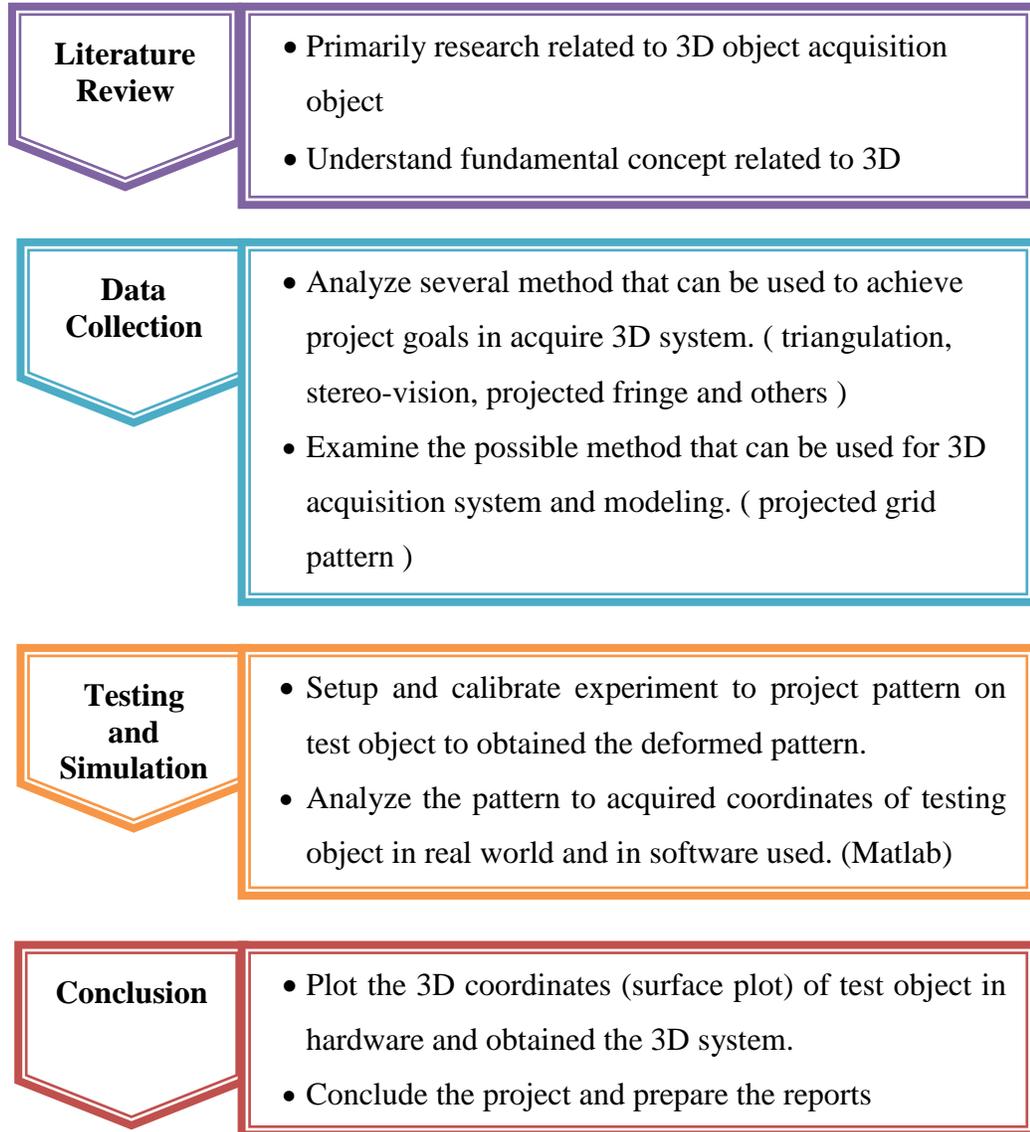


Figure 3 : Research Methodology Flowchart

3.2 Project Activities

Literature Review

The preliminary research was conducted to gather material regarding 3D system. Research papers related to the 3D object acquisition system being studied and review. The fundamental concept related to the 3D system as well as its application being understand intensely.

Data Collection

Based on the research papers that being studied, data regarding 3D system being analyze. The method and procedure in obtaining the 3D system being studied and understand. Several methods that being found such as triangulation, stereo-vision, projected fringe will help author in dealing with the 3D system. Plus, the comparison between the methods also will help the author to chose the best method as reference. In this case, author already decided to chose simple structured light method in order to find the 3D coordinates.

Testing and Simulation

By using the structured light method, specific pattern such as dots and grid line being project on the test object like cube or sphere. By using this method, the pattern on the object surface will deformed according to the surface of test object. The change of the pattern form on the object's surface then will be capture by the camera. However, the best pattern need to be determine first and the simple experiment was conducted to see the suitable pattern deformation image based on test pattern that being projected by using the projector. Then, calibrated experiment need to be done in order to obtain all the necessary and accurate data that will be use in the software analysis and simulation.

Conclusion

In analyzing the deformed pattern image using the software, several simulation and algorithm may be create in order to determine the exact point and coordinates of the test object. After coordinates can be determine, the 3D object acquisition system can be achieved.

3.3 Gantt Chart

| No | Description of Activities | Period Of Planning (Week) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----|-----------------------------------|---------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|
| | | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | | |
| 1 | Allocation Project Title | █ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Research Work & Literature Review | | █ | █ | █ | █ | █ | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Conduct Experiment | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | | | | |
| 4 | Analyze Result Of Experiment | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | | | | | |
| 5 | Obtained Tabulated Data | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | | | | | |
| 6 | Analyze Data | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | | | | | |
| 7 | Software Development | | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | |
| 8 | Final Completion For Software | | | | | | | | | | | | | | | | | | | | | | | | | █ | █ | █ | | | |
| 9 | Report/Thesis Project | | | | | | | | | | | | | | | | | | | | | | | | | | | █ | █ | █ | █ |

Table 1 : Gantt Chart

3.4 Key Milestone

| No | Description of Activities | Period Of Planning (Week) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----|--|---------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| | | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | |
| 1 | Allocation Project Title | █ | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Literature Review on 3D System Acquisition | | █ | █ | █ | █ | █ | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Find Experiment Equipment | | | | | | | █ | █ | | | | | | | | | | | | | | | | | | | | | |
| 4 | Conduct Experiment | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | | |
| 5 | Obtained 3D Coordinates | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | | |
| 6 | Analyze and Tabulated Data | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | | | | | | |
| 7 | Analyze Data Coordinates with MATLAB | | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | | |
| 8 | Acquire 3D coordinates system and surface plotting | | | | | | | | | | | | | | | | | | | | | | █ | █ | █ | █ | █ | █ | | |
| 9 | Finalize Report | | | | | | | | | | | | | | | | | | | | | | | | | | █ | █ | █ | █ |

Table 2 : Key Milestone

CHAPTER 4

RESULT AND DISCUSSION

4.1 Preliminary Design

This chapter will focus the preliminary design in order to complete the objective and achieved goal for this project. However, this is not valid design since all the parameter do not fully configured. The objective of the experiment is basically want to test and compare the different types of projected pattern using projector.

Three types of pattern being made to be projected on the test object. These pattern involve grid and dots. These pattern will be projected on the test object and the pattern that falls on the object being captured by the camera. The captured images then being observe and compare. The patterns are shown in figures below.

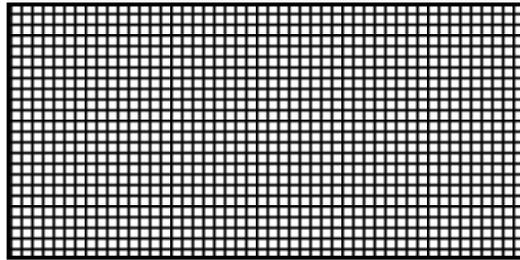


Figure 4 : Pattern 1 for Black Grid with White Background Pattern

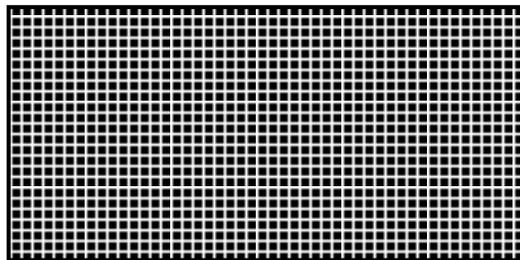


Figure 5 : Pattern 2 for White Grid with Black Background Pattern

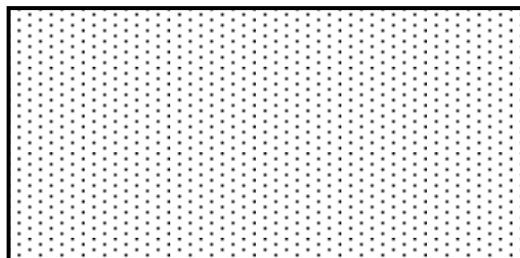


Figure 6 : Pattern 3 for Black Dots with White Background

To test the three patterns that being decided, a projector was used to project the desired pattern at each time to the test object. The projected pattern then will falls and make pattern on the test object. The deformation of the projected pattern then being captured to acquire the pattern deformation image. This deformation pattern then being compare to see the best projected pattern to chose for achieving the 3D coordinates.

However, to obtain precise data to be analyze, the experiment need to be calibrated. All the distance parameter must be recorded. The angle of camera also need to be fixed in order to get vivid image. The distance of the test object also will increase step by step with fixed increment to get the depth of the object. The experiment can be conduct as shown in the figure below.

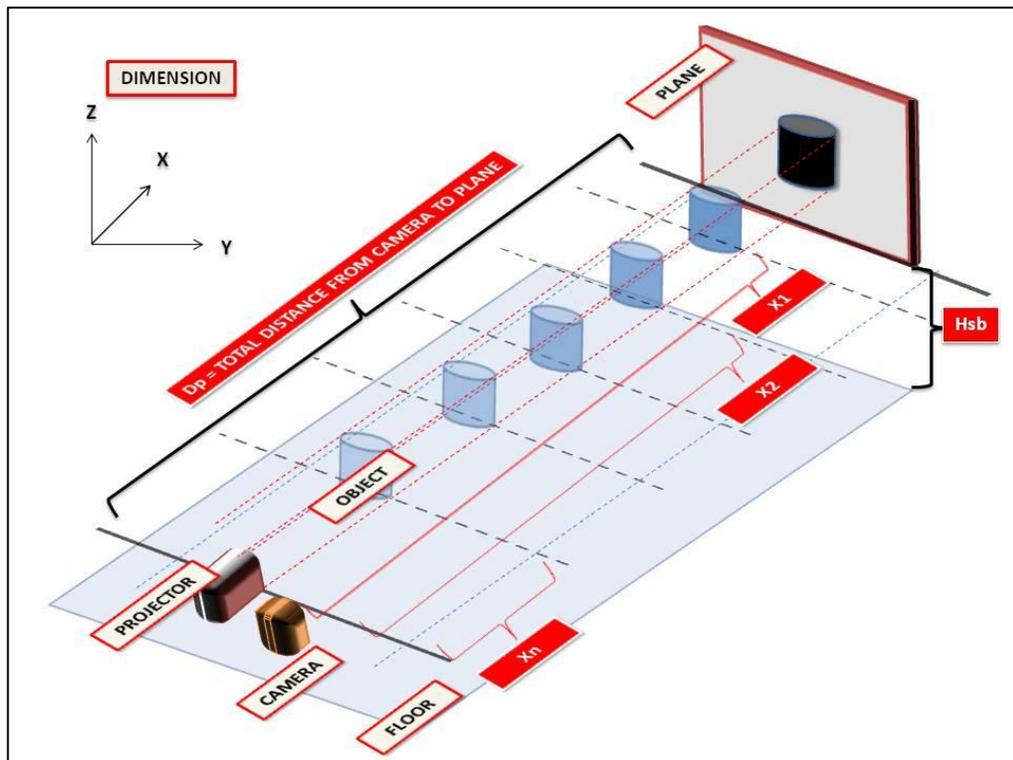


Figure 7 : Layout of Calibrated Experiment

4.2 Calibrated Experiment

For this section, the experiment was calibrated to reduce error in collecting data. There are several modification that should be made while conducting the experiment for data collection such as defining the coordinates system in real world. For this experiment, the coordinates system for XYZ-plane being define in relation with the camera position. The information regarding the coordinate can be seen in figure below.

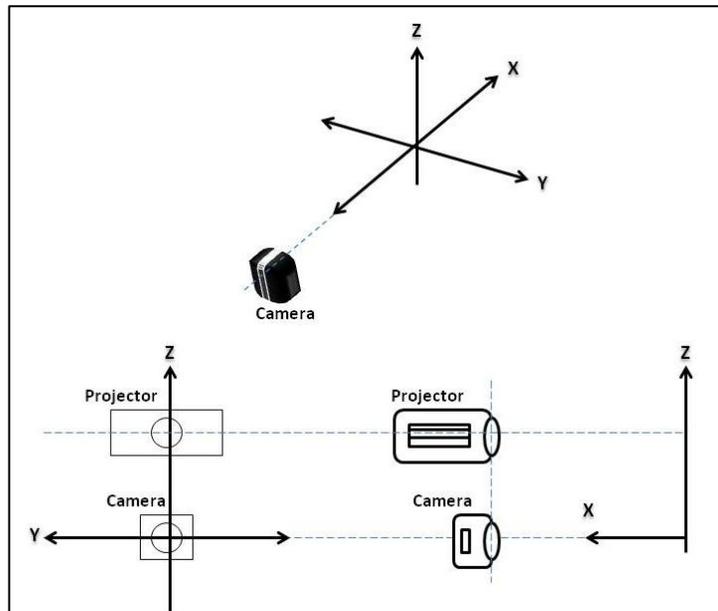


Figure 8 : Defining The Coordinates System

Other than that, the indices stripe or scale also need to be calibrated and fixed. The position of stripes will indicate the exact location of pattern used in relation with the scale that already being fixed. The center of the camera's position will also indicate the origin of the XYZ-plane. The indices are assign to planes that originates from the projector. But, as for simplicity, the indices being indicates based on the position of the camera. The example of indices scale can be seen in figured below.

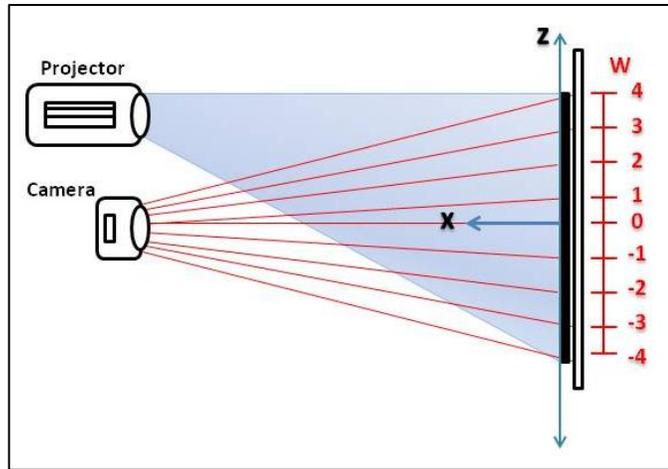


Figure 9 : Assigning Stripe Indices

All the measurement must be properly assign with standard variable for data collection. This calibrated experiment will help to eliminate error for interpolation process data later on. The experiment should be setup as shown in the figure below.

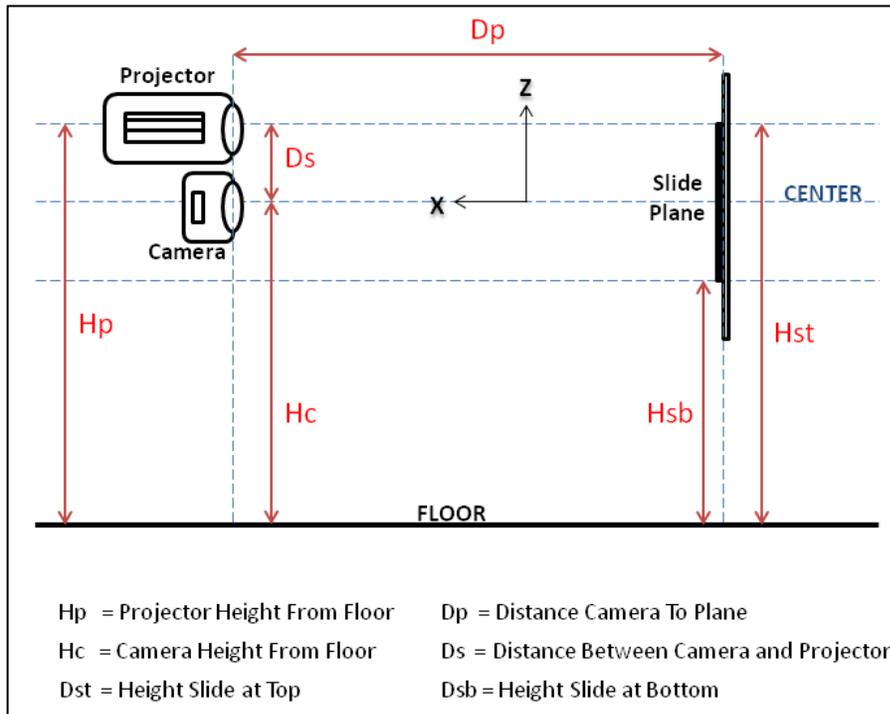


Figure 10 : Variable For Measurement

For interpolation propose related with the pattern capture on the surface of the object, the process can be done by measuring and recorded the variation of size that

form on the test object. By moving the object closer to the camera, variety of same pattern size can be captured and analyze. From the data, interpolation process can be carried out by constructing new data point within the known range that already being fixed. With the help of the indices scale that being fixed, the size measurement of pattern can be exactly determine. For example, with object movement of two centimeter from original position of YZ-plane towards camera, the pattern captured will magnified two times from the original. This variation of data will help with the 3D construction process later. The procedure describe being shown below.

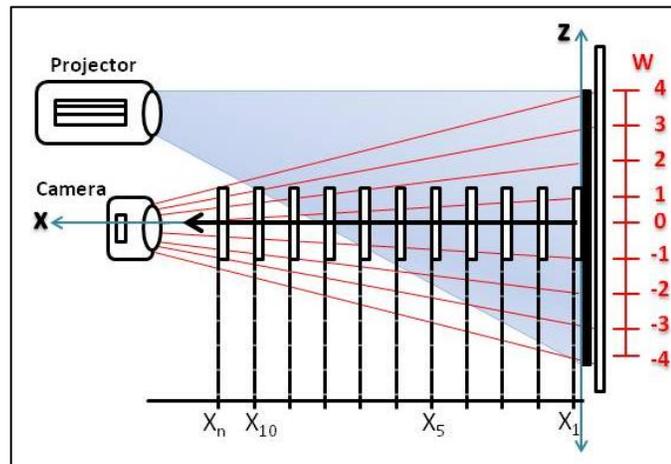


Figure 11 : Moving Test Object Toward Camera

In order to capture all the object pattern, the camera must be able to see the overall picture of test object. With this, overall pattern that deformed on the object can be capture. To do this, distance between projector and camera must be smaller as possible. For better understanding, the process being shown below.

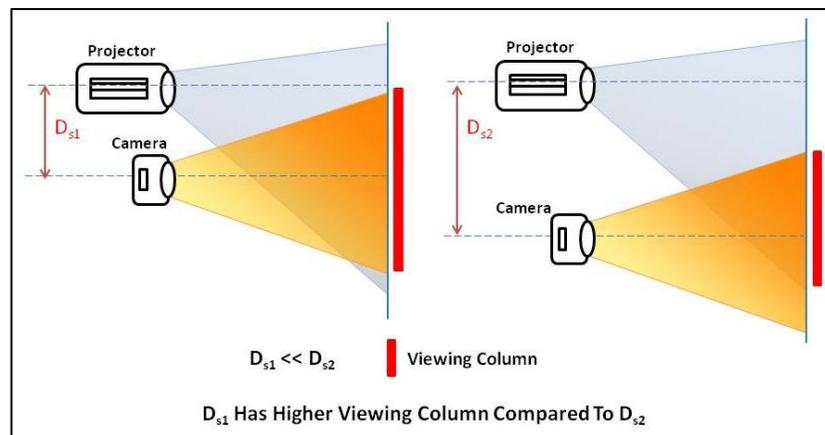


Figure 12 : Lower Distance Projector and Camera Give Higher Viewing Column

4.3 Result and Discussion For Preliminary Experiment

The simple experiment were conducted to see the pattern deform on the surface after being projected by using simple projector light. Based on the result, the best pattern was chosen between the three patterns that being projected on the tested subject. The three different project patterns can be seen below.

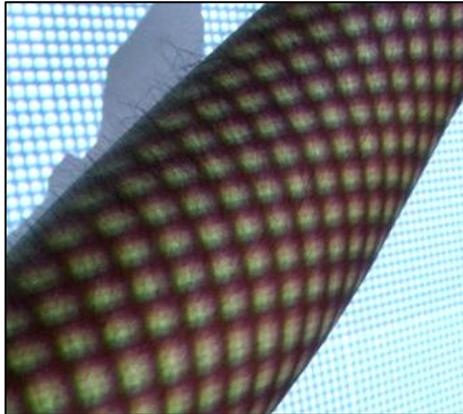


Figure 13 : Pattern 1 for Black Grid with White Background Pattern

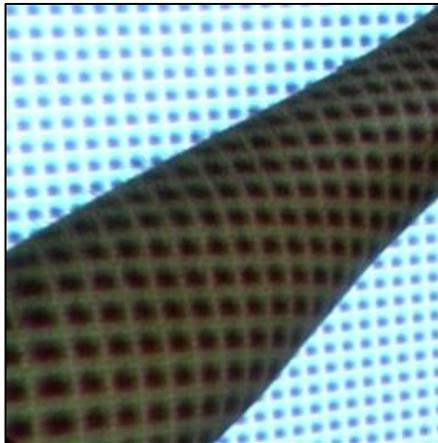


Figure 14 : Pattern 2 for White Grid with Black Background Pattern

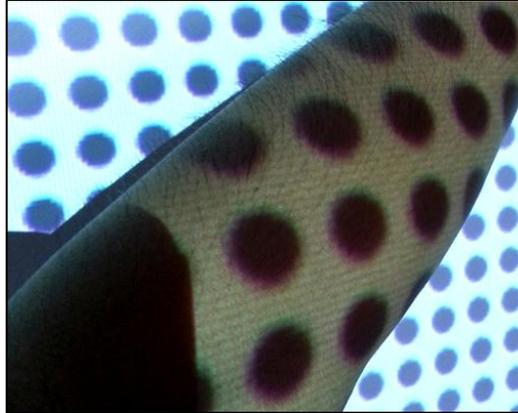


Figure 15 : Pattern 3 for Black Dots with White Background

Three projected pattern was put on the test that are pattern 1 for black grid with white background, pattern 2 for white grid with black background and pattern 3 for black dots with white background. For pattern 1 (figure 13), the black grid can be seen clearly on the test object. The deformation of straight line to slight curvy line can be seen when the pattern falls on the curve surface of the test object. Clear and vivid black straight line pattern important for analyze purposes using the software later on.

For pattern 2 (figure 14), white lines grid become slightly curve when falls on the curve surface. However, the white lines cannot be seen clearly when the image being analyze. Thus, pattern 2 is not suitable pattern to choose for obtaining the coordinates. For pattern 3 (figure 15), although the black dots can be seen clearly on the capture image, but the overall pattern still hard to determine since the dots become larger over distances. However, the location of deformed dots will indicates the exact coordinates of each point that being falls and deformed on the object.

Based on the result obtained and deformation of pattern, the best pattern that being used after comparison is the pattern 3. This is due to the deformation pattern that can be seen on the test object. Due to the important of data collection in determining the exact location of deformed points, pattern 3 is choose.

4.4 Result and Discussion For Calibrated Experiment

This section will explain and discuss of the result obtained from the calibrated experiment. This calibrated experiment was conducted to record data for pattern size with the change or movement of object along the X-plane nearer to the camera. The pattern size were manually measured and recorded in table. The setup experiment was shown as below.

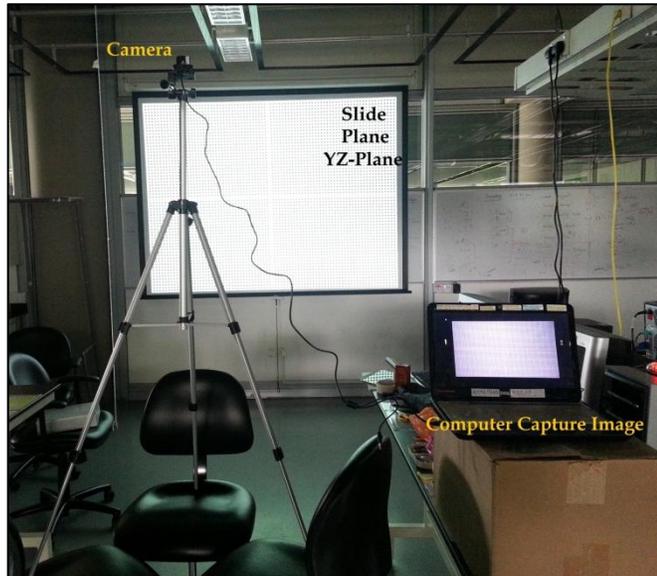


Figure 16 : Experiment Setup

The original captured picture was shown below. For this experiment, since the grid was too small for detection, black dots were used in collecting data and coordinates. The diameter of the dots were manually measured and recorded in the table.

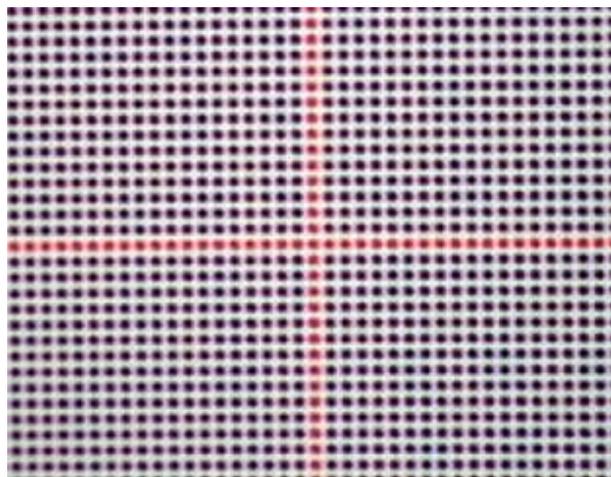


Figure 17 : Picture Captured By Camera Without Object



Figure 18 : Picture Capture By Camera With Test Object (Box)

As the test object being forward nearer to the camera, the diameter of black dots pattern were recorded was tabulated in the table. Supposedly, with the increment of fixed value from the YZ-plane (refer figure 11), the dots become larger as the object moves towards camera. Basically, the objective is to record the diameter size of the black dots and new set of data can be form for interpolation process later on. The diameter of dots were manually measured by using ruler.

By referring to figure 11, the first measurement that was made from 15 cm from YZ-plane. After placing the test object (white box) along with stand, the diameter of dots along with number of dots that lay on the box were recorded. The increment were adjusted to 20 cm for next measurement since there were not so much changed being recorded below 20 cm. the capture image by the camera were shown below.



Figure 19 : Object 15 cm from YZ-Plane



Figure 20 : Object 35 cm from YZ-Plane



Figure 21 : Object 55 cm from YZ-Plane

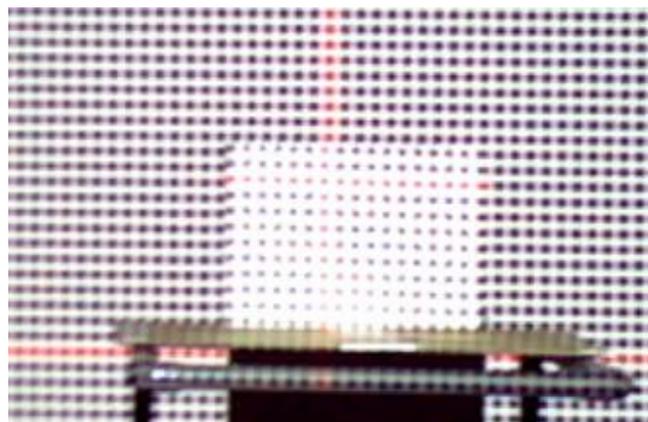


Figure 22 : Object 115 cm from YZ-Plane

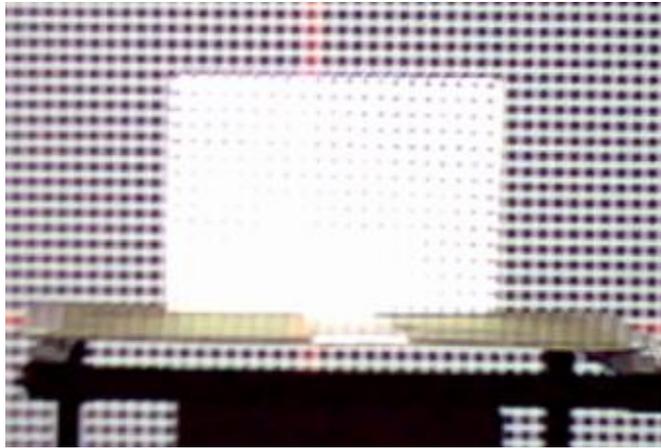


Figure 23 : Object 175 cm from YZ-Plane



Figure 24 : Object 215 cm from YZ-Plane

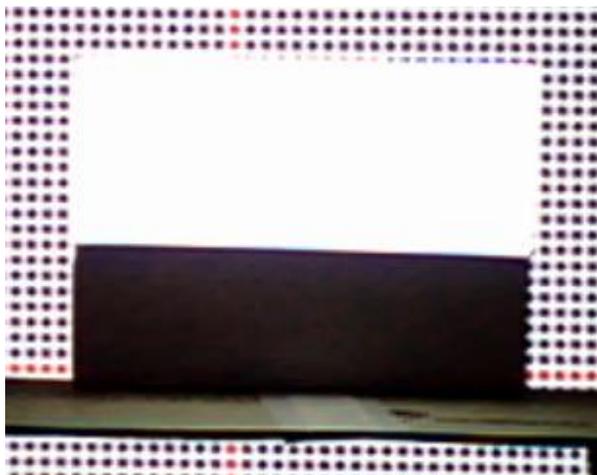


Figure 25 : Object 235 cm from YZ-Plane

By referring to figure 25, the picture shows the test object with black shadow covering the lower part of the object. This happened due to the surface of test object that is not being covered by the projector ray projection light. Plus, the measurement for dots that lays on the object also will be out of range. The resulting picture shows the object distance of 255 cm from YZ-plane which shows shadow covering almost of the surface.



Figure 26 : Object 255 cm from YZ-Plane

Noted that the overall distance from YZ-plane to camera and projector is 400 cm. The result were tabulated in the table below.

| X_0 | Distance From Camera (cm) | Diameter of circle (cm) | Number of Dots Cover The Box Height | Number of Dots Cover The Box Length |
|----------|---------------------------|-------------------------|-------------------------------------|-------------------------------------|
| X_1 | 385 | 1.8 | 9 | 12 |
| X_2 | 365 | 1.8 | 9 | 12 |
| X_3 | 345 | 1.7 | 9 | 12 |
| X_4 | 325 | 1.7 | 9 | 14 |
| X_5 | 305 | 1.4 | 10 | 15 |
| X_6 | 285 | 1.4 | 12 | 17 |
| X_7 | 265 | 1 | 12 | 17 |
| X_8 | 245 | 0.9 | 13 | 18 |
| X_9 | 225 | 0.8 | 15 | 21 |
| X_{10} | 205 | 0.7 | 16 | 24 |
| X_{11} | 185 | 0.6 | 18 | 28 |
| X_{12} | 165 | 0.5 | Out Of Range | 29 |
| X_{13} | 145 | Out Of Range | Out Of Range | Out Of Range |

Table 3 : Tabulated Measurement Data Result

There are several things that can be highlight from the calibrated experiment based on the result data that already being recorded. Firstly, there are maybe error occur while recording the diameter of the dots on the test object surface. This parallax error may comes from unclearly dot pattern that were display. In other words, the dot were not vivid enough to show the exact position of outer diameter of the circle dots.

Secondly, as the test object nearer with the camera, the dots pattern become more vivid and causing only white object being capture at the distance 215 cm (refer figure 25). Noticed also from result recorded in table 3, the height and length of dots that cover the test object increases with the distance.

Thirdly, the size of circle diameter also increases with distance. Supposedly, in theory, the dots will increases in size as the distance become nearer to the camera (refer to figure 11). However, from the result obtain, the size of the dots decreases as the distance increases. This happened due to vividness of the circle as the object approaching the camera. As the circle become clearer, it is easy to measured the diameter of dots.

Supposedly, the data that being gathered for this calibrated experiment can be used for depth reconstruction process to determine the exact depth of the test object. The number of dots present at the surface of the object can be used in producing polynomial function that could tell the depth of the test object with respect of the distance being captured. However, based on the tabulated table, it can be seen that total number of dots that cover the object does not produce so many differences as the number almost the same as although the distance capture increases. Luckily, by using the concept of pixel depth resulting from this experiment also, depth reconstruction of the test object can be made possible.

4.5 Depth Reconstruction Of Test Object

4.5.1 Pixel Offset Method

This section will explain the method to get the depth of object under test. The analysis start with single image with projected pattern onto it. Based on the pattern deformation on the surface of the object, the offset of the dots line will be measured. Then, data of the offset being used to reconstruct the object under test. With the help of MATLAB software, the image being analyze and the coordinates of each pixel can be determine manually. The coordinates then being used to reconstruct the 3D image of the respective object.

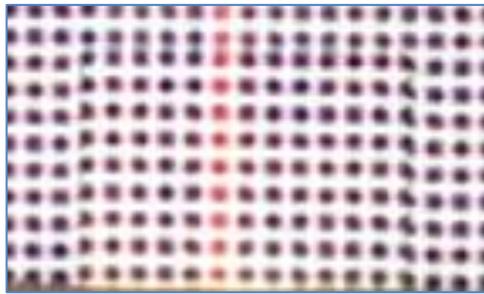


Figure 27 : The Original Image With Object

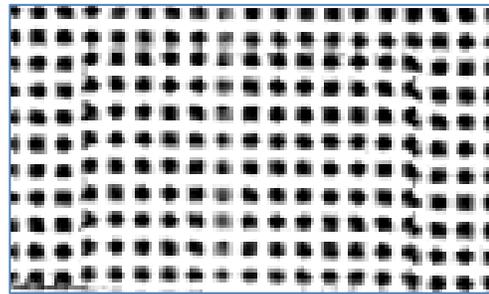


Figure 28 : Original Image After Sharpen

The coordinates of each pixel in the image then being analyze to reconstruct the exact 2D representative coordinates of the image. Then, by manually count the pixels that offset from the original dots line, the depth of the object can be determine. By referring to the Figure 29, there only two upper straight dots line that not offset (not fall onto the test object surface). Other lines show slightly offset from the original straight line. By manually count the offset and after taking the average offset value which is equal to 5 pixel, the 2D and 3D representative of the object can be determine.

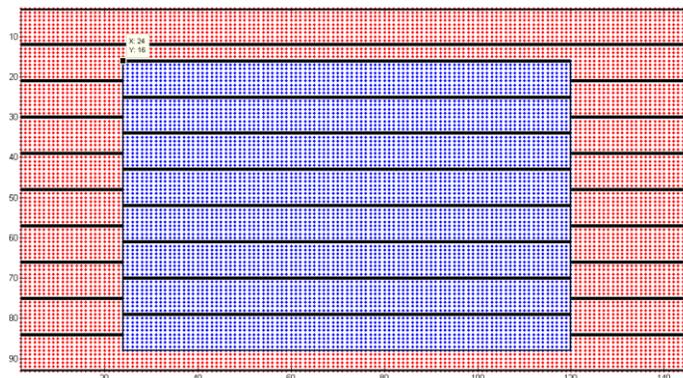


Figure29 : 2D Reconstruction Image Of

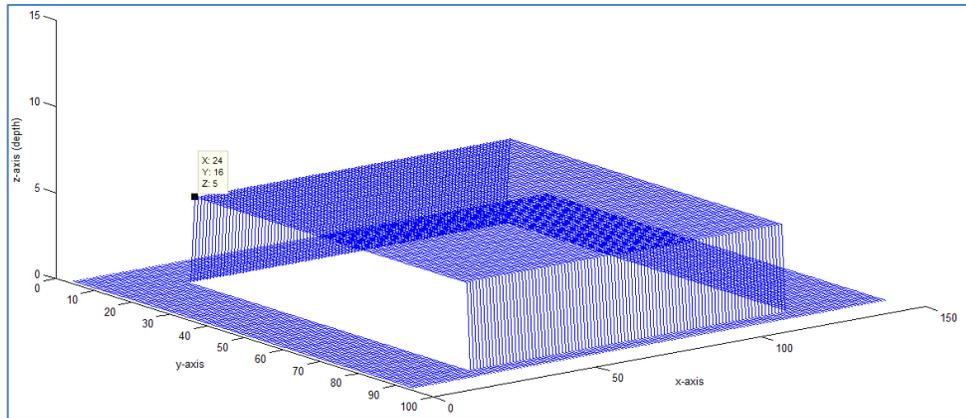


Figure 30 : 3D Representation Of The Test Object

Although the representative of the 3D object can be determine manually from the coordinates point, however the result is not accurate because the dimension is not same with the real object. By assuming and manually count the offset for the capture image, the result somehow can be vary with the distance of the object with the camera. The overall MATLAB coding shown in the appendix A.

4.5.2 Interpolation Approach

This section will explain the method to acquire an estimation of depth. The idea involve with the mapping the Pixel Depth of the object photograph in the image with the Real Depth of the object with an interpolation function. In order to find the parameter of the interpolation function, a set of measurement with predefined distance from the camera was used, and then the distance from the bottom of the test object (indicate origin line) in the image is calculated.

4.5.2.1 Defining the Pixel Depth

The pixel depth of the test object in the image is defined as the distance of the bottom of the test object to the top edge of the image. For simplicity, the pixel depth of image can be calculated as follow:

$$\text{Pixel Depth} = R - r$$

where

R = The size of the image

**r = The distance of the bottom
of test object to the top
image edge**

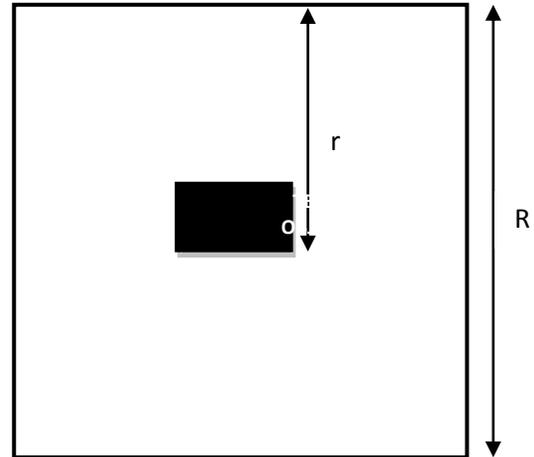


Figure 31 : The Pixel Depth

4.5.2.2 Defining The Real Depth

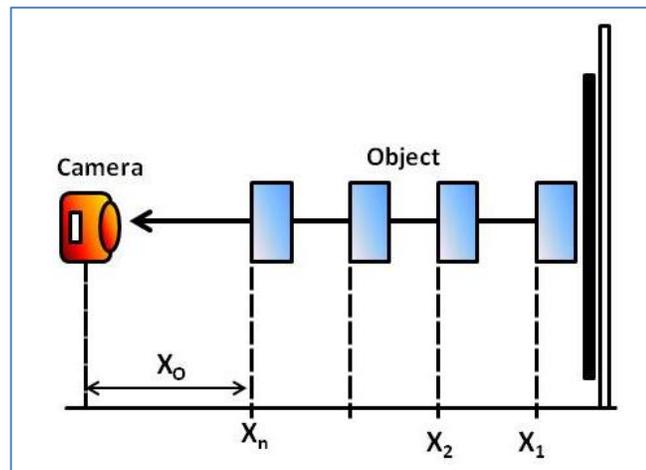


Figure 32 : The Real Depth

The Real Depth of the test object is defines as the horizontal distance between the camera position and the test object that being photograph. The camera is maintained in the horizontal position at fixed height above the ground. The point X_0 indicate the distance of the camera to the position of test object as it move closer towards the camera. The distance become the furthest at X_1 and start to decreases as it become closer to the camera.

4.5.2.3 Image Acquisition and Analysis With Polynomial Interpolation

From the concept of polynomial interpolation, which mean interpolation of data set by a polynomial with given some point, the polynomial need to be defined which goes exactly through all the given points. In this case, it is desired to devise a polynomial that can take the pixel depth of test object in image and gives as output, the actual distance between the object and the camera, the real depth. The derivation of the polynomial simply implies the calculation of the coefficients of the various terms X^n (polynomial degree). Once the polynomial completely derived and all the coefficients are known, the polynomial itself become intelligent system to calculate the real depth of particular image with the condition of pixel depth is also provided.

To calculate the polynomial coefficients, it is required to have sample set that include sample images taken in such a manner that the distance of the object is constantly varying in each image. This sample set of image then being analyzed and the pixel depth of the image is tabulated against the real depth that was measured while taking the pictures with the help of a measuring tape.

The tabulation of data after analysis of images being done and the result as shown in the table below. Noted that, the maximum distance between the object and the camera is 400 cm.

| X_0 | Distance From Camera, Real Depth (cm) | Pixel Depth (R - r) | R | r |
|----------|---------------------------------------|---------------------|-----|-----|
| X_1 | 385 | 266 | 480 | 214 |
| X_2 | 365 | 265 | 480 | 215 |
| X_3 | 345 | 263 | 480 | 217 |
| X_4 | 325 | 260 | 480 | 220 |
| X_5 | 305 | 259 | 480 | 221 |
| X_6 | 285 | 257 | 480 | 223 |
| X_7 | 265 | 256 | 480 | 224 |
| X_8 | 245 | 253 | 480 | 227 |
| X_9 | 225 | 250 | 480 | 230 |
| X_{10} | 205 | 238 | 480 | 242 |
| X_{11} | 185 | 230 | 480 | 250 |
| X_{12} | 165 | 225 | 480 | 255 |
| X_{13} | 145 | 215 | 480 | 265 |

Table 4 : Tabulated Data Of Real Depth and Pixel Depth

The data in the table include thirteen click images that being analyze and processed with the Image Processing Tool in MATLAB. The recorded observations are given as input into the MATLAB and with the help of a curve fitting tool, a curve is obtained for the particular set of data. (All the thirteen click images are shown appendix B)

The obtained curve is unique to the particular camera from which the pictures had been captured and with the constant height of the camera. Any image that being taken with the same parameter from the camera can now be directly analyzed from this curve. After that, polynomial approximation being applied to the curve and an N degree polynomial can be obtained for the set of data values. Since, the curve fitting MATLAB tool automatically calculates the coefficients and hence, the polynomial can be derived.

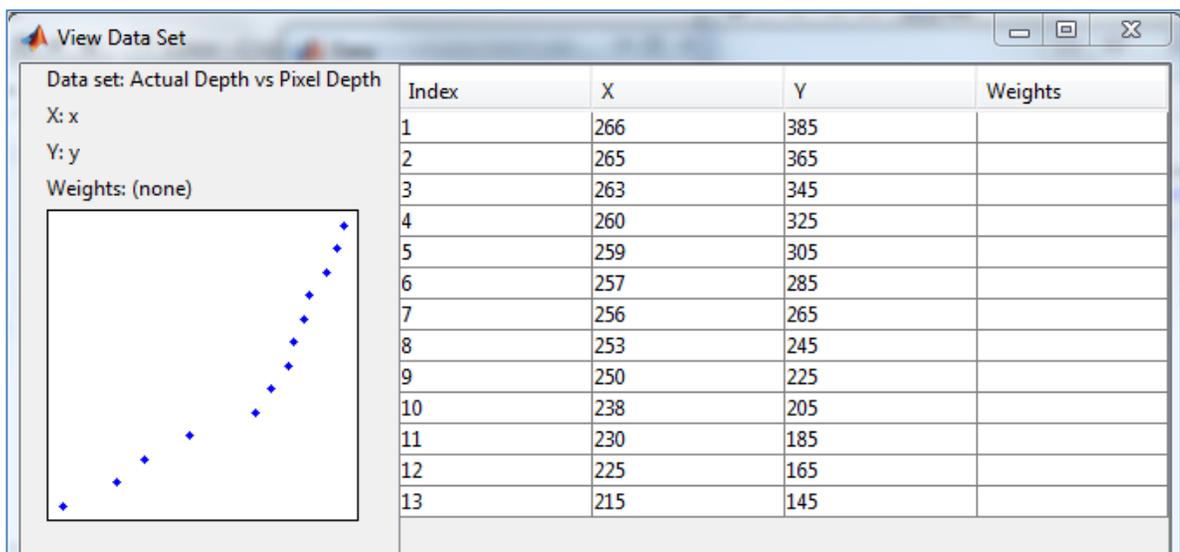


Figure 33 : Data Set Value In MATLAB

From the analysis with the MATLAB Curve Fitting Tool, it was found that for the listed set of data, the 8th degree polynomial give the best fit. This also indicate the root mean square error (RMSE) is minimum for the given approximation. Hence, the 8th degree interpolation function is shown in the following figure.

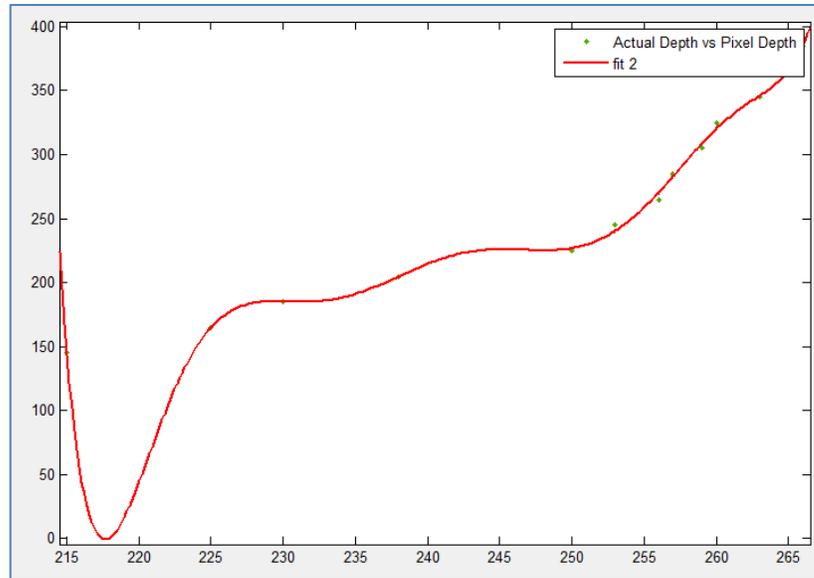


Figure 34 : Curve Fitting Through Points

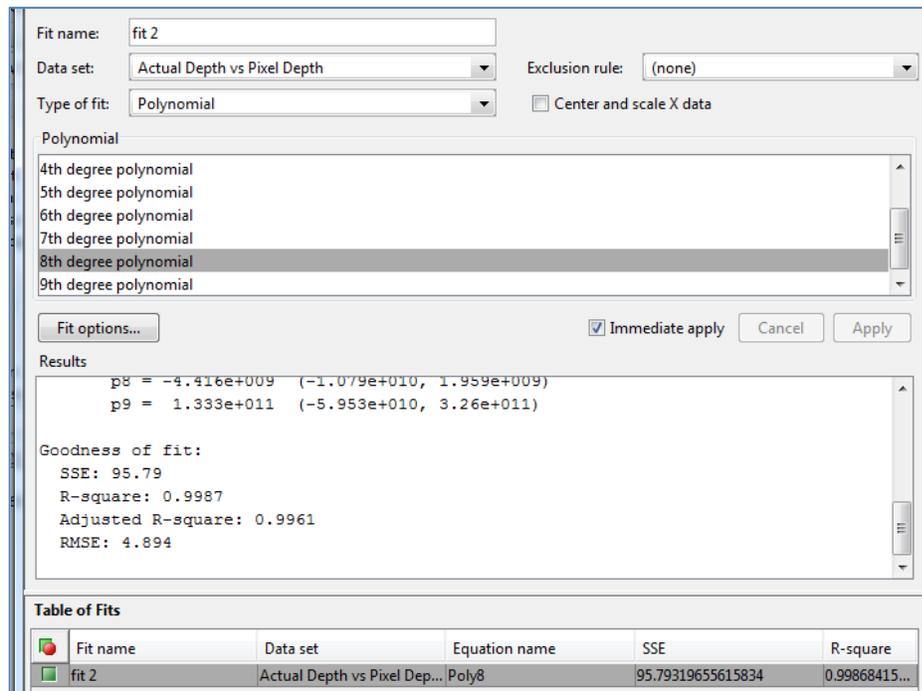


Figure 35 : Data Fitting

Linear model Poly8:

$$f(x) = p1x^8 + p2x^7 + p3x^6 + p4x^5 + p5x^4 + p6x^3 + p7x^2 + p8x + p9$$

Coefficient:

$$p1 = 1.132e-008 \ (-4.777e-009, 2.741e-008)$$

$$p2 = -2.197e-005 \ (-5.329e-005, 9.342e-006)$$

$$p3 = 0.01865 \ (-0.007986, 0.04528)$$

$$p4 = -9.036 \ (-21.97, 3.898)$$

$$p5 = 2735 \ (-1188, 6658)$$

$$p6 = -5.293e+005 \ (-1.29e+006, 2.316e+005)$$

$$p7 = 6.398e+007 \ (-2.819e+007, 1.562e+008)$$

$$p8 = -4.416e+009 \ (-1.079e+010, 1.959e+009)$$

$$p9 = 1.333e+011 \ (-5.953e+010, 3.26e+011)$$

Goodness Of fit:

RMSE: 4.894

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The aim of the project is to obtain 3D object acquisition system for the tested object. Pattern were use to project towards the plane by using the simple light projector. Three patterns was chosen to be projected on the test object. The pattern deformation then being capture using the camera as the test object move closer to the camera. Based on the capture images, analysis being made using software for data tabulation. The data also comes from calibrated experiment that being conducted. All the gathered data then will be used to construct back the test object in the form of 2D and 3D. The data also will be used to acquire the interpolation function (polynomial equation) based on the images captured. This interpolation very essential in determining the depth of the test object. As the polynomial function already being determine, the real depth of the test object can be known by using same equation.

For this experiment, the position of the projector already being fixed and mount at higher position due to unavoidable reason. The recommendation is that, in constructing this 3D system, the position of the projector should be moveable with the camera used. The distance between projector and camera also should be small as possible to avoid higher occlusion effect. Higher occlusion effect mean the viewing area not large enough to see the overlapping area of projector with camera range. Since, the position of projector already being fixed, thus camera should be high as possible and nearer to projector so that the capture pattern can be record precisely. Besides, the camera that being used also need to be in high resolution so that the pattern image that being captured were vivid and ease for any analysis.

REFERENCES

- [1] G. Tognola, M. Parazzini, P. Ravazzani, F. Grandori, and C. Svelto, "3D-coordinate measurement system and image reconstruction of anatomical parts from unorganized data clouds," in Instrumentation and Measurement Technology Conference, 2004. IMTC 04. Proceedings of the 21st IEEE, 2004, pp. 487-490 Vol.1.
- [2] J. Tao, "Face Reconstruction Based on Camera-Projector System," in Industrial Control and Electronics Engineering (ICICEE), 2012 International Conference on, 2012, pp. 1026-1029.
- [3] D. Moreno and G. Taubin, "Simple, Accurate, and Robust Projector-Camera Calibration," in 3D Imaging, Modeling, Processing, Visualization and Transmission (3DIMPVT), 2012 Second International Conference on, 2012, pp. 464-471.
- [4] C. Diaz and L. Altamirano, "Dense 3D surface acquisition using projected fringe technique," in Computer Science, 2004. ENC 2004. Proceedings of the Fifth Mexican International Conference in, 2004, pp. 116-123.
- [5] L. Lijun, K. Yingjie, and J. Kaiyong, "Surface Reconstruction Based on Computer Stereo Vision Using Structured Light Projection," in Intelligent Human-Machine Systems and Cybernetics, 2009. IHMSC '09. International Conference on, 2009, pp. 451-454.
- [6] K. Peng, L.-b. Liu, and X.-l. Zhou, "Error Analysis and Compensation of 3D Coordinate Measuring System by Watching an Image of Object," in Image and Signal Processing, 2009. CISP '09. 2nd International Congress on, 2009, pp. 1-5.
- [7] C. Chang Woo, H. Sungjoo, and J. Soon Ki, "Calibration-free approach to 3D reconstruction using light stripe projections on a cube frame," in 3-D Digital Imaging and Modeling, 2001. Proceedings. Third International Conference on, 2001, pp. 13-19.
- [8] M. A. Tehrani, A. Saghaeian, and O. R. Mohajerani, "A New Approach to 3D Modeling Using Structured Light Pattern," in Information and Communication Technologies: From Theory to Applications, 2008. ICTTA 2008. 3rd International Conference on, 2008, pp. 1-5.

- [9] C. Byeong-Mook, P. Yoon-Chang, and D. Jin-Yeong, "Phase-height relationship by plane analysis in 3D shape measurement using fringe pattern projector," in *Sensors Applications Symposium (SAS)*, 2014 IEEE, 2014, pp. 272-277.
- [10] S. Mohan, K. B. Simonsen, I. Balslev, V. Kruger, and R. D. Eriksen, "3D scanning of object surfaces using structured light and a single camera image," in *Automation Science and Engineering (CASE)*, 2011 IEEE Conference on, 2011, pp. 151-156.
- [11] S. Zhan and C. R. Chung, "Determining Both Surface Position and Orientation in Structured-Light-Based Sensing," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 32, pp. 1770-1780, 2010.
- [12] C. Kazo and L. Hajder, "High-quality structured-light scanning of 3D objects using turntable," in *Cognitive Infocommunications (CogInfoCom)*, 2012 IEEE 3rd International Conference on, 2012, pp. 553-557.
- [13] P. Lavoie, D. Ionescu, and E. M. Petriu, "3D object model recovery from 2D images using structured light," *Instrumentation and Measurement, IEEE Transactions on*, vol. 53, pp. 437-443, 2004.
- [14] J. Yuan Hui, Q. Liu Chun, J. Yu, I. Yang, and S. Yin, "Study on 3D measurement and merge technology based on color stripes permutation encoding," in *Strategic Technology (IFOST)*, 2011 6th International Forum on, 2011, pp. 1082-1085.
- [15] S. Mahadevan, H. Pandzo, M. Bennamoun, and J. A. Williams, "A 3D acquisition and modelling system," in *Acoustics, Speech, and Signal Processing, 2001. Proceedings. (ICASSP '01). 2001 IEEE International Conference on*, 2001, pp. 1941-1944 vol.3.
- [16] K. Deelip Wagh, "Fast 3D modelling using orthographic views," in *Information Science, Electronics and Electrical Engineering (ISEEE)*, 2014 International Conference on, 2014, pp. 1842-1845.

APPENDIX A

MATLAB Coding For Depth Reconstruction Using Pixel Offset Method

```
%-----CREATE ORIGINAL PATTERN POINTS-----  
data1 = [2 : 146];  
data2 = [3 : 93];  
[Data1, Data2] = meshgrid (data1, data2);  
  
%-----CREATE GRID INSIDE OBJECT-----  
data1ob = [24 : 120];  
data2ob = [16 : 88];  
[Data1ob, Data2ob] = meshgrid (data1ob, data2ob);  
figure( 'color', [1 1 1]), imshow(gray16dcc);           %change BG to yellow  
plot(Data1,Data2,'r. '); %plot original pattern points red colour  
set(gca,'YDir','reverse'); % set y-axis positive go down  
title('RECONSTRUCT OF EACH PATTERN POINT WITH OBJECT','fontweight','bold','fontsize',16)  
axis([2 146 3 93]);  
hold on  
  
%-----DRAW HORIZONTAL LINE OVER POINT---START-----  
xL = get(gca,'XLim');  
line(xL,[3 3],'Color','k','LineWidth',4);           %line1  
line(xL,[12 12],'Color','k','LineWidth',4);       %line2  
%line(xL,[21 21],'Color','k','LineWidth',4);  
%line(xL,[30 30],'Color','k','LineWidth',4);  
%line(xL,[39 39],'Color','k','LineWidth',4);  
%line(xL,[48 48],'Color','k','LineWidth',4);  
%line(xL,[57 57],'Color','k','LineWidth',4);  
%line(xL,[66 66],'Color','k','LineWidth',4);  
%line(xL,[75 75],'Color','k','LineWidth',4);  
%line(xL,[84 84],'Color','k','LineWidth',4);  
line(xL,[93 93],'Color','k','LineWidth',4);       %line11
```

```

line([2 24], [21 21],'Color','k','LineWidth',4);           %line3i
line([120 146], [21 21],'Color','k','LineWidth',4);       %line3ii
line([2 24], [30 30],'Color','k','LineWidth',4);          %line4i
line([120 146], [30 30],'Color','k','LineWidth',4);       %line4ii
line([2 24], [39 39],'Color','k','LineWidth',4);          %line5i
line([120 146], [39 39],'Color','k','LineWidth',4);       %line5ii
line([2 24], [48 48],'Color','k','LineWidth',4);          %line6i
line([120 146], [48 48],'Color','k','LineWidth',4);       %line6ii
line([2 24], [57 57],'Color','k','LineWidth',4);          %line7i
line([120 146], [57 57],'Color','k','LineWidth',4);       %line7ii

line([2 24], [66 66],'Color','k','LineWidth',4);          %line8i
line([120 146], [66 66],'Color','k','LineWidth',4);       %line8ii

line([2 24], [75 75],'Color','k','LineWidth',4);          %line9i
line([120 146], [75 75],'Color','k','LineWidth',4);       %line9ii

line([2 24], [84 84],'Color','k','LineWidth',4);          %line10i
line([120 146], [84 84],'Color','k','LineWidth',4);       %line10ii

plot(Data1ob,Data2ob,'b. ');                               %plot object point
%set(gca,'YDir','reverse');                                 % set y-axis positive go down
%axis([2 146 3 93]);
%hold on

%-----DRAW RECTANGLE BOX, OBJECT-----
xstart = 24;
ystart = 16;
xlen = 96;
ylen = 72;
rectangle('position', [xstart, ystart, xlen, ylen],'edgecolor','k','LineWidth',2);

```

```

%-----DRAW HORIZONTAL LINE WITHIN RANGE ON OBJECT----- x x y1 y2
line([24 120], [16 16], 'Color', 'k', 'LineWidth', 4);           %line 3
line([24 120], [25 25], 'Color', 'k', 'LineWidth', 4);           %line 4
line([24 120], [34 34], 'Color', 'k', 'LineWidth', 4);           %line 5
line([24 120], [43 43], 'Color', 'k', 'LineWidth', 4);           %line 6
line([24 120], [52 52], 'Color', 'k', 'LineWidth', 4);           %line 7
line([24 120], [61 61], 'Color', 'k', 'LineWidth', 4);           %line 8
line([24 120], [70 70], 'Color', 'k', 'LineWidth', 4);           %line 9
line([24 120], [79 79], 'Color', 'k', 'LineWidth', 4);           %line 10
%line([24 120], [88 88], 'Color', 'k', 'LineWidth', 4);           %line 11

```

```

%----CREATE Z-COORDINATES ON OBJECT--ARRAY SAME SIZE AS X AND Y COORDINATES-----
z3d = 5 * ones(91,145); %edit data z3d so that data only exist on surface of object and save data

```

```

%-----PLOT SURFACE TEST OBJECT-----
figure( 'color', [1 1 1]), imshow(gray16dcc);                    %change BG to yellow;
plot3(Data1,Data2,z3d,'b');
set(gca,'YDir','reverse');                                       % set y-axis positive go down
title('COORDINATES WITH DEFORMED PATTERN POINT', 'fontweight', 'bold', 'fontsize', 16)
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis (depth)')
zlim([0 15])

```

APPENDIX B

Thirteen Click Images That Being Used In Interpolation Method



