TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO.:069MSCS653

A

THESIS REPORT

ON

3D Object Modeling by Phase Shifting Profilometry

A Performance Comparison Between Sinusoidal and Saw-tooth Fringe Pattern

SUBMITTED BY:

Bikram Kumar KC

069/MSCS/653

SUBMITTED TO THE DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING AS A PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN COMPUTER SYSTEM AND KNOWLEDGE ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING

LALITPUR, NEPAL

NOV, 2016

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By

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer System and Knowledge Engineering

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Lalitpur, Nepal

Nov, 2016

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RECOMMENDATION

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis report entitled "**3D MODELING BY PHASE SHIFTING PROFILOMETRY; A PERFORMACE COMPARISON BETWEEN SINUSOIDAL AND SAW-TOOTH FRINGE PATTERN**" submitted by **Bikram Kumar KC** in partial fulfillment of the requirements for the degree of Master of Science in Computer System and Knowledge Engineering.

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DEPARTMENTAL ACCEPTANCE

The thesis entitled "**3D Modeling by Phase Shifting Profilometry; A performance Comparison Between Sinusoidal and Saw-tooth Fringe Pattern**", submitted by **Bikram Kumar KC** in partial fulfillment of the requirement for the award of the degree of "**Master of Science in Computer System and Knowledge Engineering**" has been accepted as a bonafide record of work independently carried out by him in the department.

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ABSTRACT

The 3D reconstruction of rigid objects using Phase Shift Profilometry(PSP) technique is one of the cornerstones of computer vision. Intensive research have been carried out on optimizing algorithm to increase the accuracy and efficiency. Different experimental results have been presented using different fringe patterns.

So, this thesis work primarily focuses on experiment to find the characteristics of fringe patterns and their effect on 3D reconstruction in identical condition. Two fringe patterns sinusoidal and saw-tooth have been taken for comparison. This thesis work presents the comparative result of 3D reconstruction in different objects. Experiment was done on two rigid objects dummy mannequin head and triangular shaped piece of wood.

Keywords: *Phase Shift Profilometry, Digital fringe projection, 3-D reconstruction, Phase wrapping, Phase unwrapping.*

ACKNOWLEDGEMENT

I would like to express my deep gratitude to Department of Electronics and Computer Engineering for providing this platform for research work.

I am grateful to all faculty members for their encouragement and valuable guidance during the thesis title selection phase and special thanks goes to Prof. Shashidhar Ram Joshi for his great supervision.

I am also thankful to all my classmates for their suggestions and comments regarding this thesis work.

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LIST OF ABBREVIATIONS

PSP	Phase Shift Profilometry
DMD	Digital Micro-mirror Device
MEMS	Micro Electro Mechanical System
MSE	Mean Square Error

CHAPTER 1: INTRODUCTION

1.1 Background

Three-dimensional reconstruction of small objects has been one of the most challenging problems over the last decade. Computer graphics researchers and photography professionals have been working on improving 3D reconstruction algorithms to fulfill the high demands of various real life applications [1]. Both lack of accuracy and high computational cost are the major challenges facing successful 3D reconstruction. Recent progress in digital imaging has greatly boosted three-dimensional measurements of objects. As the technology advancement is going on, the methods of 3D surface measurement techniques are going towards optical method from the traditional contact methods. Among the optical methods, fringe projection technique is a well-developed and most active research field for generating three-dimensional (3D) surface information. In this technique a known periodic fringe patterns, also known as 'grating', is projected on the 3D surface, which needs to be measured, are recorded by a camera. The fringe patterns recorded by a camera would be deformed because of the surface height variation. However, an algorithm of phase shifting profilometry technique can be applied to analyze the fringe patterns and retrieve a 3D surface profile distribution. This technique has found various applications in diverse fields: biomedical applications such as 3D intra-oral dental measurements, non-invasive 3D imaging and monitoring of vascular wall deformations; industrial and scientific applications such as characterization of MEMS components, corrosion analysis; biometric identification applications such as 3D face reconstruction for the development of robust face recognition systems etc [2]. This is because their ability to provide high-resolution, whole-field 3D reconstruction of objects in a non-contact manner at video frame rates [2].

There are different mathematical functions for generating grating. Following are some of them:

- Sinusoidal fringe pattern
- Saw-tooth fringe pattern
- Trapezoidal fringe pattern
- Triangular fringe pattern

Etc.

Researcher have tried different fringe pattern for attaining performance improvement. However, performance measurement and comparison under the identical environment were not found. So, this thesis work will add some perspective to evaluate the sole effect of characteristics of fringe pattern in performance.

1.2 Problem Statement

Three-dimensional reconstruction of both actual objects and the surrounding environment has always been one of the primary goals of short-range photogrammetric. This is due to the need of measuring and visualizing real world in various applications. Using sinusoidal and saw tooth fringe projection, reconstructing the mannequin head in identical environment and compare the computational complexity and performance on the basis of efficiency and accuracy is the primary goal of this thesis work. The phase shifting profilometry (PSP) method will be deployed to efficiently reconstruct the 3-D object.

1.3 Objectives

- To reconstruct 3-D object implementing phase shift profilometry using saw-tooth and sinusoidal fringe pattern.
- Compare the result in terms of accuracy

1.4 Scope of the Work

The scope of thesis work is to implement the phase shift profilometry methodology to reconstruct the 3-D image using two different fringe patterns. And compare the effect of fringe patterns. Basically, it includes steps like image acquisition, phase wrapping, phase unwrapping and 3-D rendering. Extra algorithm and error correction methodology has not been applied.

1.5 Organization of Report

The chapter 1 of thesis report is Introduction that describes briefly about Phase Shift Profilometry and its background. It describes about the problem definition and objective of the thesis work and scope of it.

Chapter 2 basically includes the relevant literature studied and referred in the course of this research work.

Chapter 3 is mainly about the methodology implemented in the course of obtaining the objective of thesis work. It describes in detail about the Image acquisition, phase wrapping and unwrapping, phase to height conversion mechanism and rendering 3-D image and error calculation.

Chapter 4 includes the result and discussion of algorithm implementation and comparative study.

Chapter 5 includes the conclusion, limitation and recommendation for future works.

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Survey

Fringe digital mapping was first proposed by Rowe et al. [1] in 1967. Since then, it has been used in various applications in both research and industry. While, fringe projection approach employs four stages, the fringe analysis and phase detection stage will be more focused on this thesis work due to its contribution toward the success of the overall system. Phase detection has been one of the most active research areas over the last decade. It can be broadly classified into two main categories:

• Time-based analysis

• Frequency-based analysis

While the success of time-based analysis approaches highly depends on the appropriate selection of the number of phase transitions, frequency-based approaches depend on the carrier frequency. Common phase detection approaches found in literature were based on either Fourier transform [2]-[9], interpolated Fourier transform [10], continuous wavelet transform, two dimensional continues wavelet transform, discrete consign transform, neural network, phase locked loop, spatial phase detection, or phase transition [8].

Quan et al. [9] proposed the phase transition approach for small object measurement. In 2001, Berryman et al. [10] compared three different approaches (Fourier transform, phase transition, and spatial phase detection) on the reconstruction of a sphere using simulated data. Their experiments showed that in low noise conditions, phase transition produces the best results. With more than 10% noise, using Fourier transform would be a good choice. However, on high noise levels spatial phase detection showed superior results.

Suutton et al. [11] proposed a phase detection scheme based on the use of Hilbert transform with Laplacian pyramid. The proposed scheme produces high precision level.

Gdeisat et al. [12] used two-dimensional continuous wavelet transform to eliminate the low component's frequency of the fringe. Then, Fourier transform was employed for phase detection. This method offers acceptable results; taking into consideration that it uses only one fringe.

Zhang et al. [13] used a Digital Micro-mirror Device (DMD) and a projector with 40 frames per second to reconstruct a three-dimensional model using the phase transition method. They employed three separate fringe patterns in the red, green and blue channels.

LujieChen[14] used the saw tooth fringe pattern to devise the phase shift profilometry instead of sinusoidal pattern.

CHAPTER 3: METHODOLOGY

3.1 Working Principle

The model for implementing the phase shift profilometry is as depicted in following block diagram. When different fringe(sinusoidal and saw-tooth) pattern are projected on a 3-D diffuse surface, the mathematical representation of the deformed grating image intensity distribution is similar to that encountered in conventional optical interferometry. It is shown that the surface height distribution is translated to a phase distribution, and thus the methods of phase modulation interferometry, well known for their accuracy, can be used for the analysis. The working system consists of a sinusoidal grating projector and an image sensing camera, interfaced to a microcomputer system, shown in fig.3.2. The captured pattern can be analyzed to extract relevant information about the object. The data processing procedure of fringe projection is very similar to those of other optical techniques, such as laser interferometry, moire, etc. It is composed of wrapped phase extraction, phase unwrapping and carrier phase removal. Note that, the phase modulation analysis uses the arctan function, which yields values in the range [-π,+π]. Three-dimensional coordination of each pixel is computed by converting the unwrapped phase to depth (height) amplitude [2].

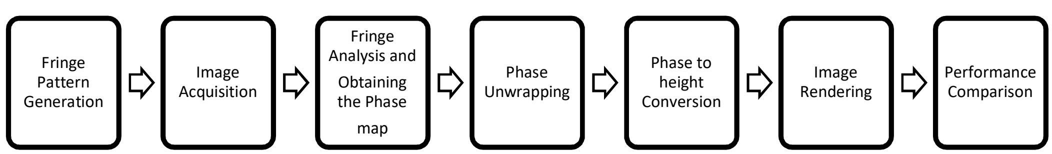


Fig. 3.1: Overall Block Diagram

3.1.1 Fringe Pattern Generation

Saw-tooth and sinusoidal fringe pattern were generated using MATLAB function plotting the varying intensity value in x-axis generating vertical stripe of frequency 1/5. Then five phase shifted pattern were generated adding phase $2\pi n/5$ each time where n = 0,1,2,3,4.

The MATLAB Equation looks like as follows:

$$i = Asin\left(\frac{2\pi x}{5} + \frac{2\pi n}{5}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

$$i = Asawtooth\left(\frac{2\pi x}{5} + \frac{2\pi n}{5}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

3.1.2 Image Acquisition

Fig. 1,2. highlights the arrangements and the major stages of a fringe projection approach, which starts with projecting a sinusoidal/saw tooth pattern over the surface of the 3D object through a multimedia projector. Then, a digital camera is used to capture the pattern that has been phase modulated by the topography of the object surface.

For Phase shifting profilometry, multiple sinusoidal/saw tooth fringe patterns were generated with phase shifts at some fixed interval MATLAB. The fringe patterns were projected one at a time over the object and the reference plane and image of the projected patterns were captured.

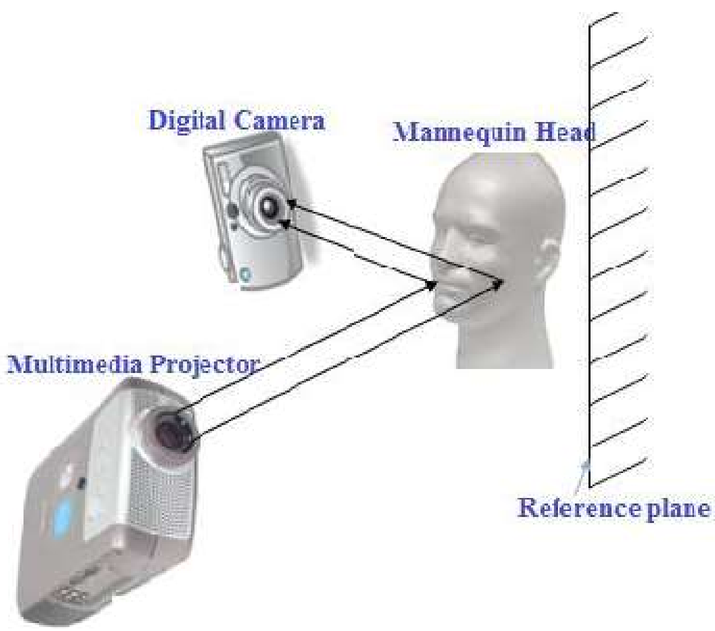


Fig. 3.2: Fringe projection profilometry system

3.1.3 Fringe Analysis and Obtaining the Phase map

Phase contains enough information about the shape of the object. Therefore, phase difference of the fringe patterns between the reference plane and the object contains strong information about shape of the object. Hence using phase-measurement techniques, the surface height relative to some reference surface can be obtained quantitatively. Thus, with the use of phase-measuring interferometry techniques, the surface height can be made relative to any surface and transformed to surface heights relative to another surface. It should also be pointed out that this measurement is sensitive to a certain direction, and that there may be areas where data are missing because of shadows on the surface. For N measurements, the total phase of the object and the reference can be calculated using following equation [3].

$$\mathrm{Tan}(\phi) = \frac{\sum_{n=1}^{N}(InSin(2\pi n/N))}{\sum_{n=1}^{N}(InCos(2\pi n/N))} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

3.1.4 Phase unwrapping principle

Fringe analysis stage computes the phase $\varphi(x, y)$ using the arctangent function which produces values in the range between –π and +π. The phase map computed by this step is called wrapped phase map. It suffers from discontinuities of values of 2π. Thus, it is necessary to identify multiples of 2π to be added to the phase value at each pixel to yield continuous phase values. This process is called phase unwrapping.

Normal phase unwrapping is carried out by matching the phase at neighboring pixels and adding or subtracting 2π to bring the relative phase between two pixels into the range of $-\pi$ to +π. Thus, phase unwrapping is a trivial task if the wrapped phase map is ideal. However, in real measurements various factors (e.g. the presence of shadows, low fringe modulations, non-uniform reflectivity of the object surface, fringe discontinuities, noise) influence phase unwrapping.

The basic flowchart of algorithm implemented for phase unwrapping is as follows:

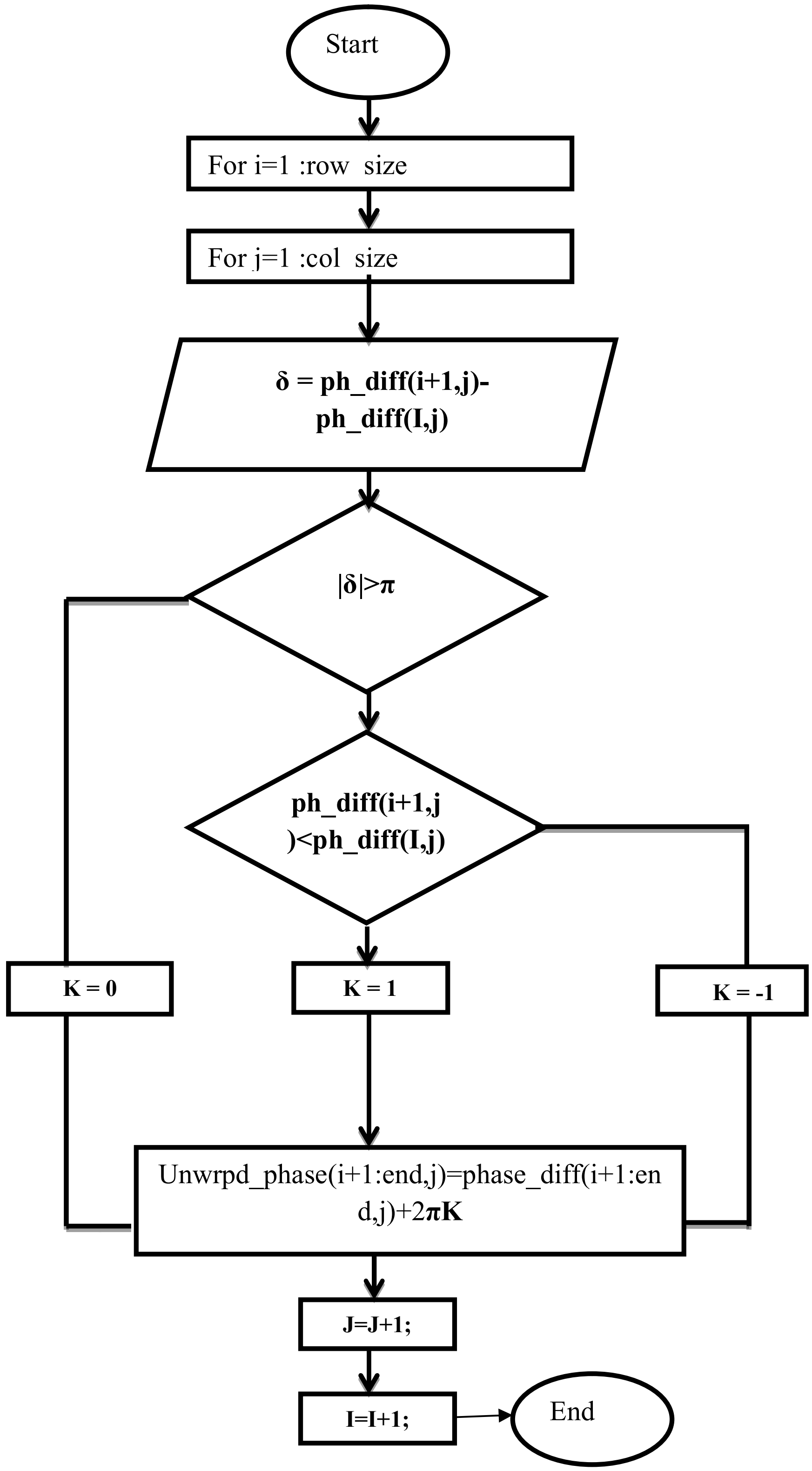


Fig. 3.3: Flowchart for Phase unwrapping

3.1.5 Phase to Height Conversion

After phase unwrapping, height information of the measured object can be extracted. here are two common approaches to calculate depth information from unwrapped phase map: relative coordinate calculation and absolute coordinate calculation. Absolute coordinate calculation approach is based on triangulation to estimate the absolute coordinate of every pixel in the world coordinate system. This approach requires precise knowledge about intrinsic and extrinsic parameters of both camera and projector. Thus, a system calibration step is essential. On the other hand, the relative approach calculates the depth of each pixel using a reference plane. It does not require a calibration process. Moreover, the relative depth calculation approach is computationally less expensive compared to the absolute approach. Fig. 3.4 shows a schematic diagram that illustrates the relative depth calculation approach. Points P and I are the perspective centers of the DLP projector and the CCD camera, respectively. The optical axes of the projector and the camera coincide at point O. After the system has been set up, a flat reference plane is measured first whose phase map is used as a reference for subsequent measurements. Then, the height of the object surface is measured relative to this reference plane.

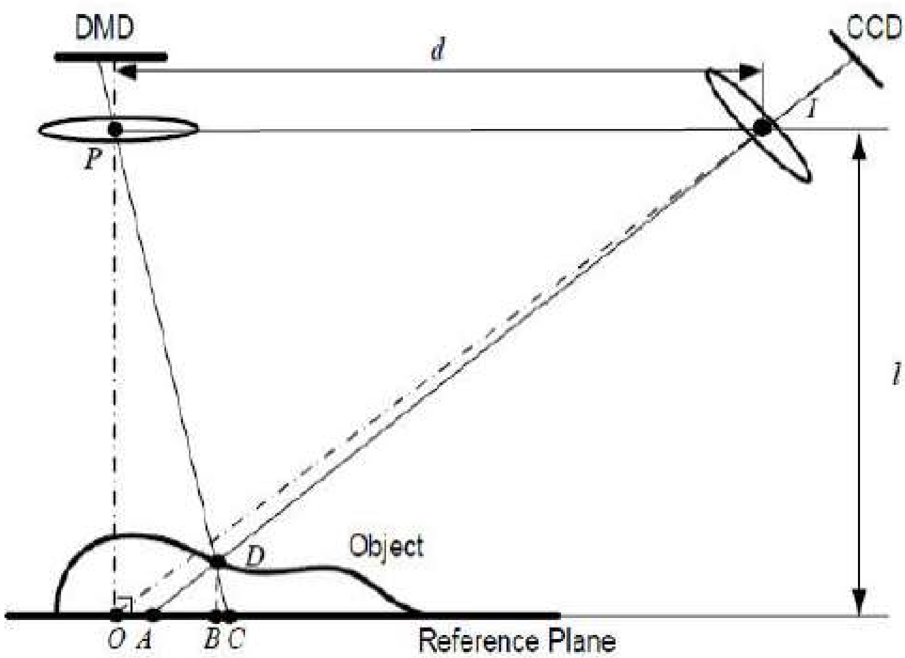


Fig. 3.4 Schematic diagram of phase-to-height conversion[1]

From the projector point of view, point D on the object surface has identical phase value as point C on the reference plane, i.e. $\Phi_D = \Phi_C$. On the other hand, from the

CCD camera point of view, point D on the object surface and point A on the reference plane are imaged on the same pixel. By subtracting the reference phase map from the object phase map, the phase difference is obtained at this specific pixel:

$\Phi_{AD} = \Phi_{AC} = \Phi_A - \Phi_C$ ....(4)

Assume that points P and I are planned to be on the equivalent plane with a distance l to the reference plane and have a distance d between them, and the reference plane is parallel to the device. Hence, the triangles PID and CAD in Fig. 3.4 are similar. Therefore:

$$\frac{d}{AC} = \frac{l - DB}{DB} = \frac{l}{DB} - 1 \quad \dots\dots\dots\dots\dots\dots\dots (5)$$

Where, d is the distance between the camera and the projector. Since d is much larger than AC for real measurement, this equation can be simplified as

$$h(x, y) = DB \cong \frac{1}{d} AC = \frac{1}{d} \Phi_{AC}/2\pi f = K.\Phi_{AC} \dots\dots\dots\dots\dots (6)$$

where, f is the frequency of the projected fringes in the reference plane, K is a constant coefficient, and Φ_{AC} is the phase containing the height information.

3.1.6 Image Rendering

Once Image is unwrapped, it is rendered using MATLAB mesh plot. Where it can be rotated in different angle. Actually, before rendering final image in each steps the image is rendered to see how it is being transformed by that step.

3.1.7 Performance Comparison

Performance comparison is based more on qualitative analysis. Mean square Error(MSE) has been calculated for the simple surface profile mapping the actual surface profile with the pixel co-ordinate.

CHAPTER 4: RESULTS AND DISCUSSIONS

Basically, there are two parts; algorithm implementation and comparative study. So, they are separately described below. The experiments were carried out on two rigid objects dummy mannequin head and triangular shaped piece of wood using two different patterns.

Since the rigid objects taken for experiments were not the standard object with the known 3D point cloud, more accurate 3D sensing devices like Kinect or Structure sensor were needed to be deployed to find the ground truth value and find the accuracy comparing the reconstruction results. Due to some complexities in mapping the feed from kinect, qualitative analysis has been done on two objects.

In case of mannequin head it is impossible to create a ground truth manually. So, piece of smooth wood having shape of triangular prism with known dimensions of reliable accuracy has been taken as shown in Fig. 4.1 placed exactly perpendicular to lens of camera in front of the reference plane. And the pixel co-ordinate in the image have been mapped to the actual object itself and created the ground truth for consideration.

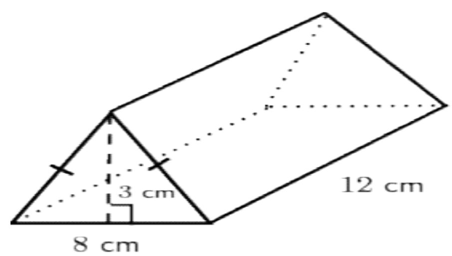


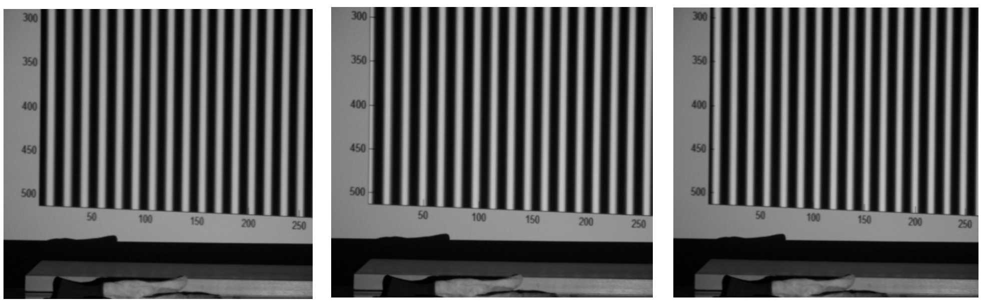
Fig. 4.1 Triangular prism with dimensions

4.1 Algorithm Implementation

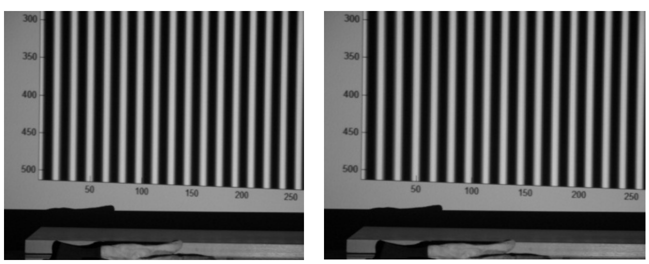
4.1.1 Image acquisition module output

The fig 4.2, 4.3 and 4.4 shows the shifted sinusoidal fringe pattern each shifted by $2\pi n/5$ projected on the reference plane mannequin head and triangular prism respectively. The fringe patterns are seemed to be inclined at a certain angle, which is due to unbalanced position of the multimedia projector. Sometimes it provides some disturbance while doing the unwrapping of the wrapped phase, but it is due to some distorted part in the image. In addition, since the phase shifting profilometry works along x and y direction, it would be better to have vertical fringe patterns images rather than inclined images. If so, those images can be rotated in a certain angle, so that vertically aligned fringe patterned image will be obtained. But the phase unwrapping algorithm has worked in both cases.

In addition, there are some shadows upon the images, which does not contain any kind of the periodic fringe information, that greatly deteriorate the result of phase unwrapping making it extremely difficult to get the desired 3D shape of object. Therefore, it needs to be trimmed image to get proper region of interest (ROI) from those images, where all trimmed images should have same matrix dimension.

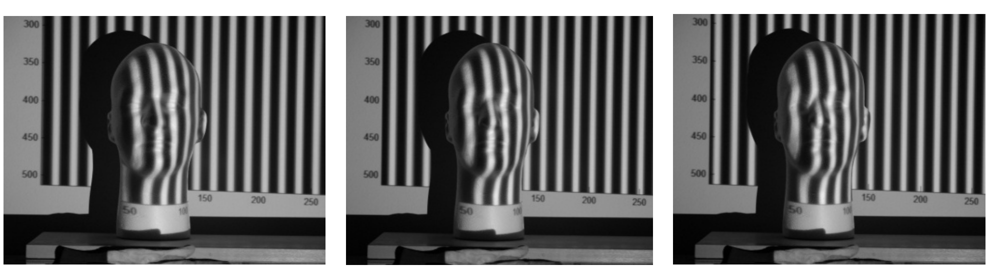


(a)n= 0 (b)n=1 (c)n=2

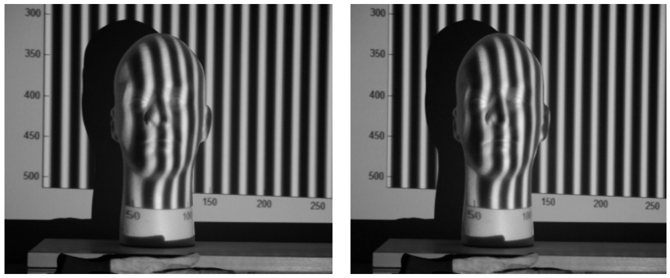


(d)n=3 (e)n=4

Fig. 4.2: Sinusoidal Pattern on Reference shifted by 2πn/5

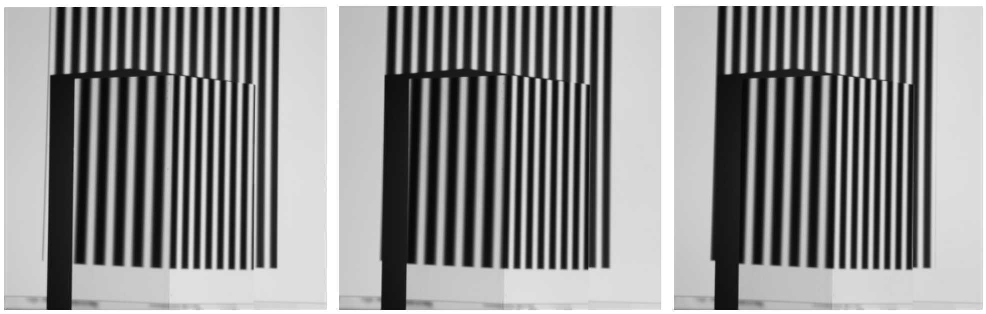


(a)n= 0 (b)n=1 (c)n=2

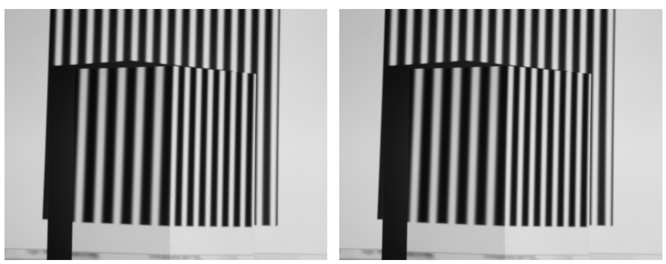


(d)n=3 (e)n=4

Fig. 4.3: Sinusoidal Pattern on mannequin head shifted by 2πn/5



a)n= 0 (b)n=1 (c)n=2



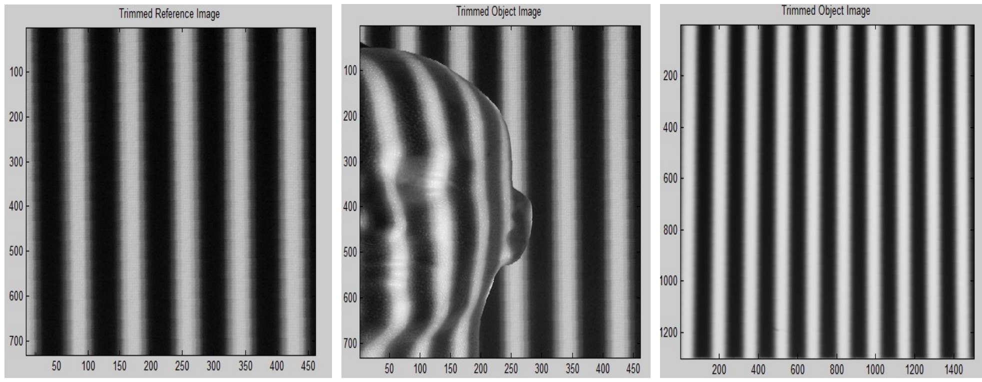
(d)n=3 (e)n=4

Fig. 4.4 Sinusoidal Pattern on Triangular prism shifted by 2πn/5

4.1.2 Phase Wrapping

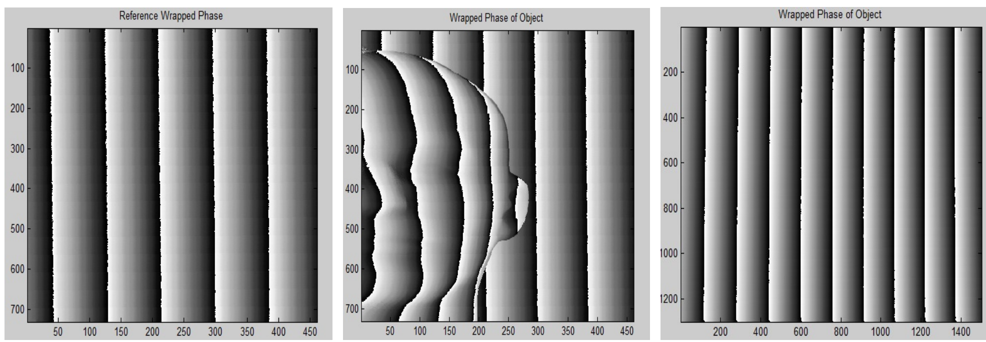
Due to unwanted effect of shadow in left side of projected image of mannequin head, trimming both reference image and object image identically appropriate region of interest has been taken before phase calculation.

Fig 4.5 shows the trimmed original reference, mannequin head and triangular prism images.



a) Reference b) Mannequin head c) Triangular Prism

Fig. 4.5. Original fringe pattern trimmed images



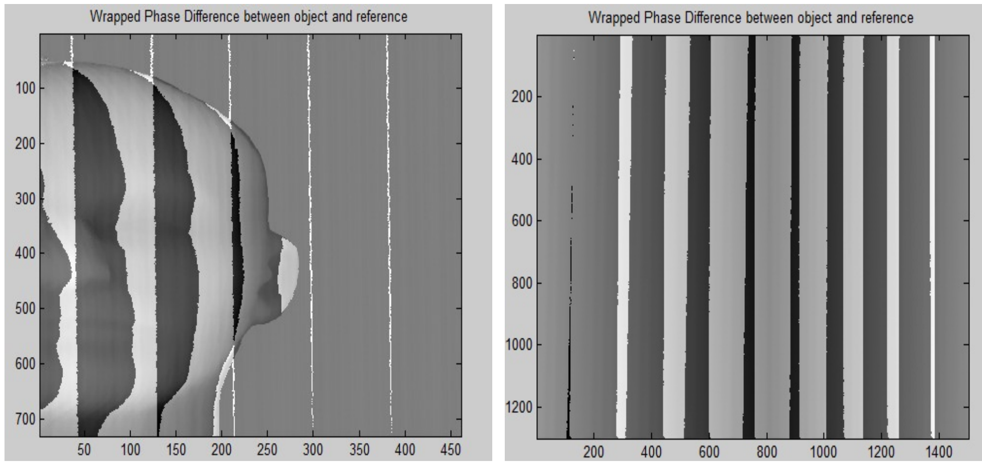
a) Reference b) Mannequin head c)Triangular Prism

Fig. 4.6.Wrapped Phase image

Fig 4.6 shows the wrapped phase images of reference, 3D mannequin head and triangular. Since the fringe patterns were projected from one angle and images were taken from another angle, the wrapped phase bars seems as thinner towards the right hand sides in comparison to left hand sides. The wrapped phase bars are also seems as inclined bars, it is due to inclined fringe patterns.

4.1.3 Phase Unwrapping

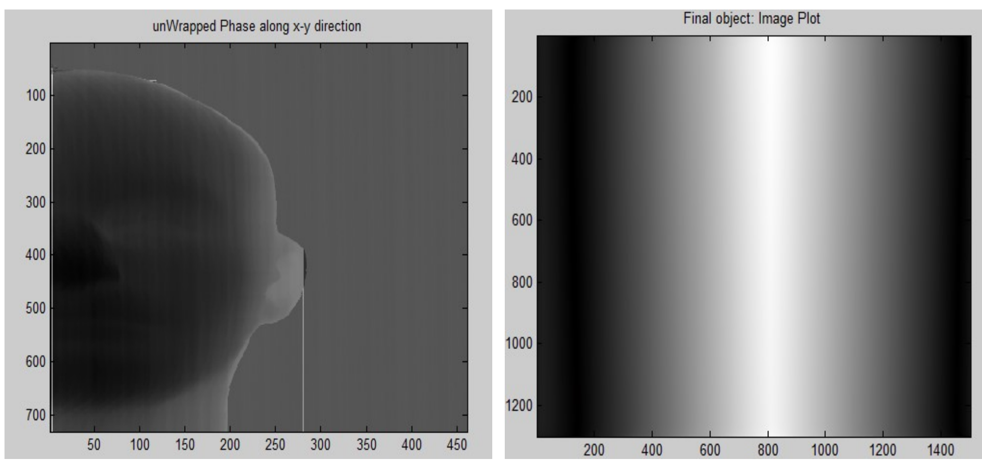
By analyzing the wrapped phase images, it can be clearly seen that the wrapped phase bars start from high intensity and get ended with low intensity part. It means, it is showing a phase jump from $-\pi$ to $+\pi$, if the phase starts from low intensity to high intensity, and vice-versa.



a) Mannequin head b)Triangular Prism

Fig. 4.7. Wrapped phase difference between object and reference

The fig 4.7 shows the phase difference of referenced plane and 3D objects. non uniform phase change can be seen due to uneven height from reference plane.



a) Mannequin head b)Triangular Prism

Fig. 4.8. Un-wrapped phase image along x-y direction

When ‘phase shifting profilometry phase unwrap algorithm is applied along x-y direction for wrapped-phase difference image mannequin head shown in fig 4.8, then some dark stripes were observed. Those dark stripes came through unbalanced fringe patterns in the ear part of the mannequin head.

Here, ear part was much brighter than the background reference image, so the black stripes or some disturbances are inevitable.

4.1.4 3-D Rendering

Fig 4.9 and 4.10 shows the 3D-plot of the mannequin head and Triangular Prism obtained after unwrapping. This is the single view reconstruction so only front views can be seen. As seen in the figure, there is no much gap or phase jumps in the ear part, as well as it is so smooth image which has given best information, instead some background part that has variation in the pixel values.

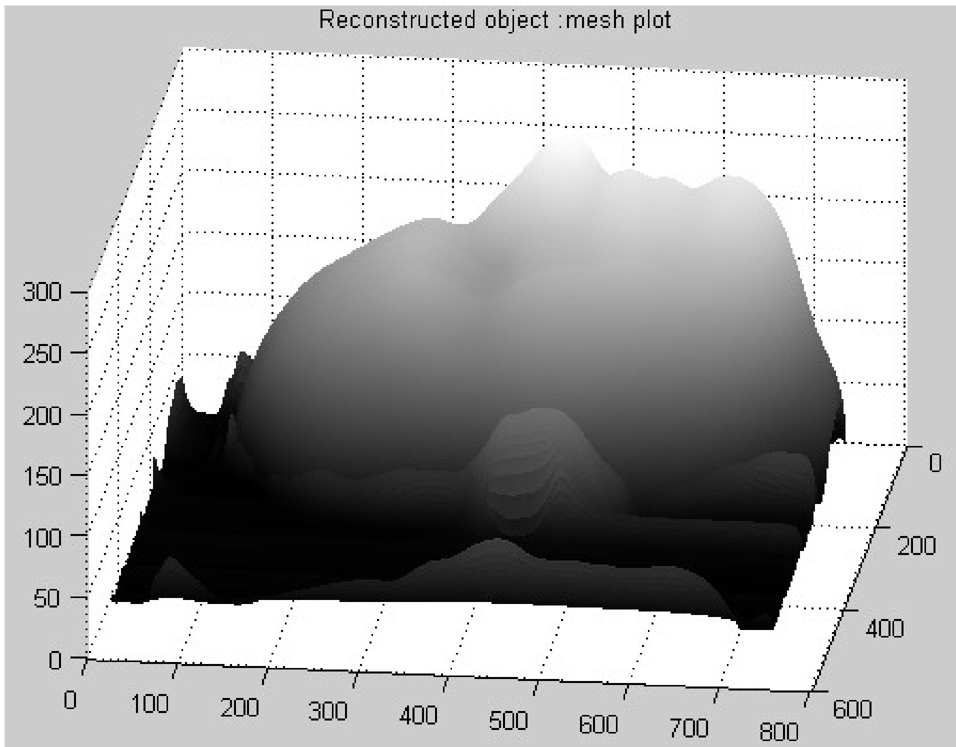


Fig. 4.9. 3D-plot of Mannequin head reconstructed

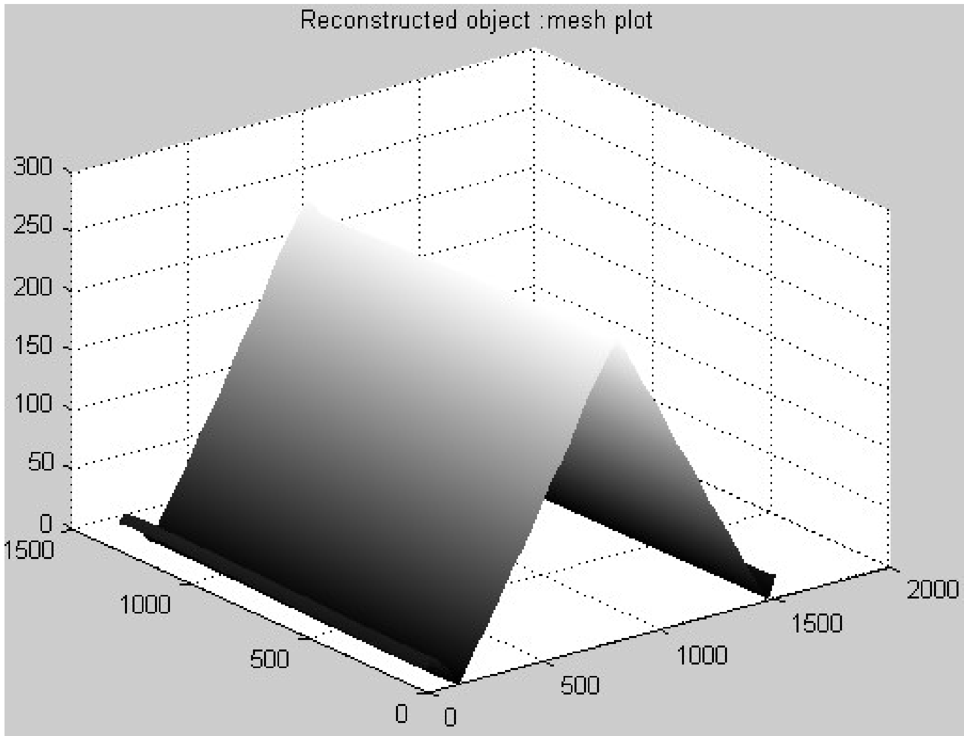


Fig 4.10 3D-plot of Triangular Prism reconstructed

4.2 Comparative Study

4.2.1 Mannequin Head

The experiments were carried out first using 5 shifted pattern for both sinusoidal and saw-tooth then output response were observed reducing the number of shifted pattern. The results were observed more accurate in higher number of shifted patterns in case of both fringe pattern. In 5 shifted pattern for both fringe the results looks identical however for lower number the sinusoidal patterns seemed to be more accurate. The results are depicted in fig 4.11 and 4.12:

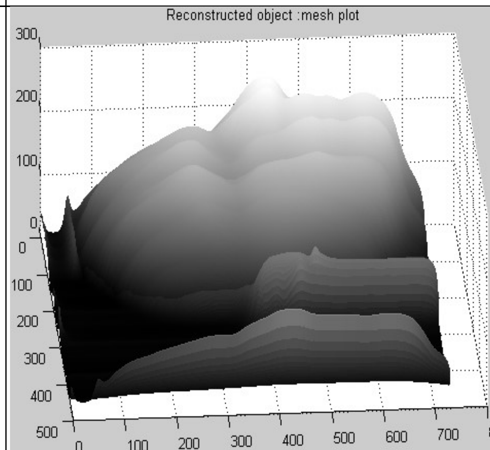
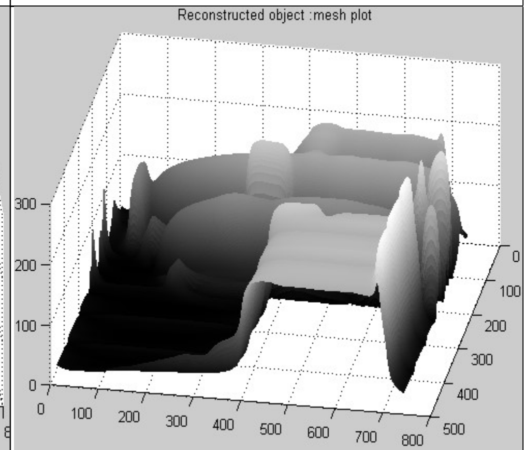
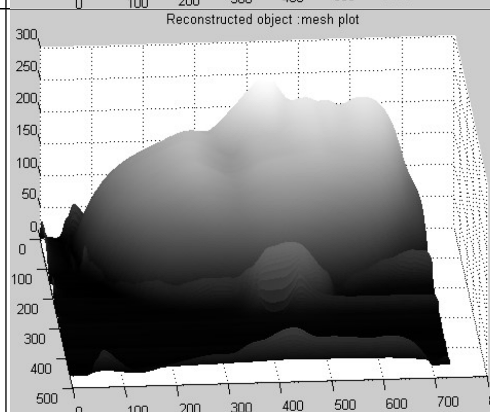
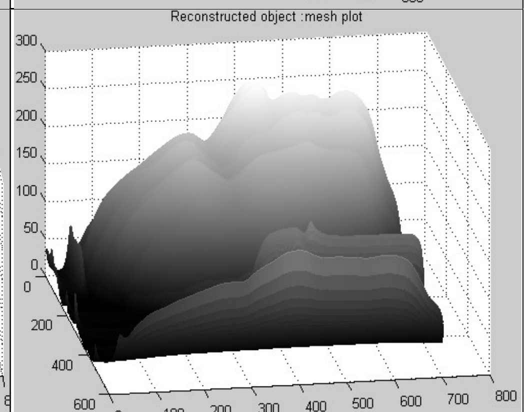
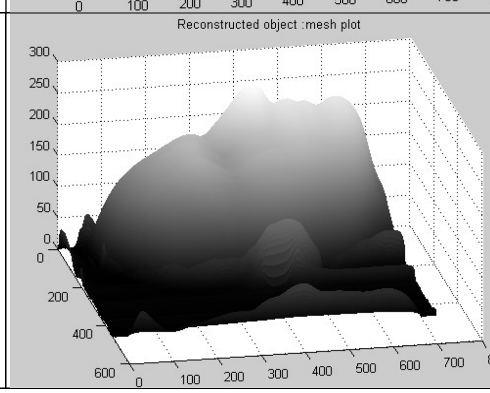
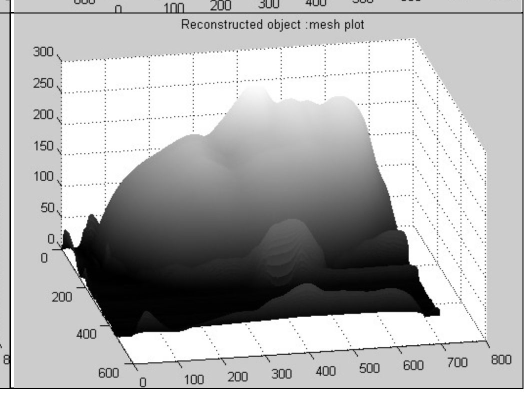
N	Sinusoidal	Saw-Tooth
3		
4		
5		

Fig 4.11 3D plot comparison for different number of phase shifted pattern

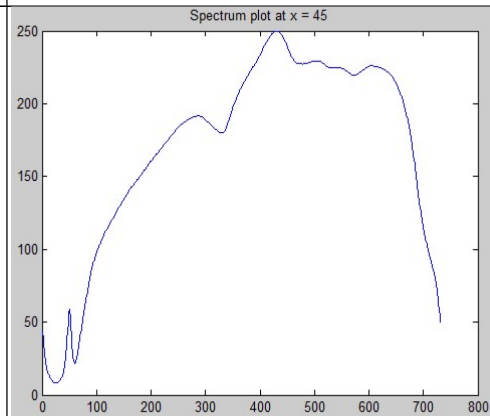
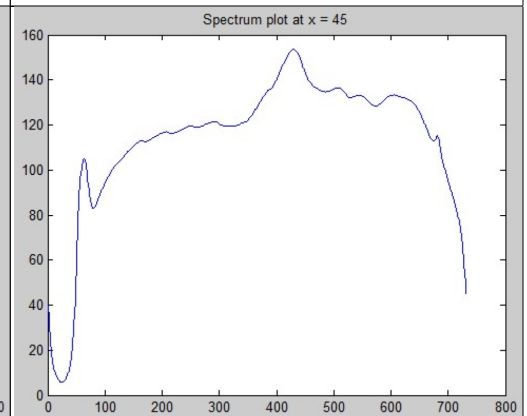
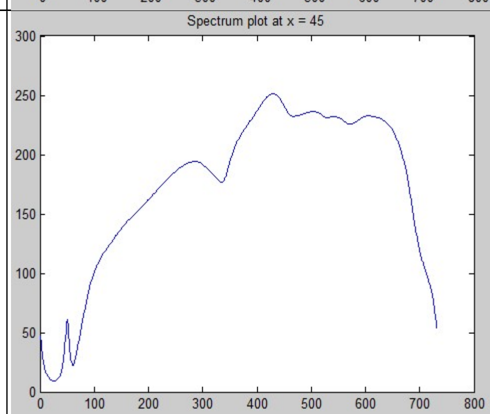
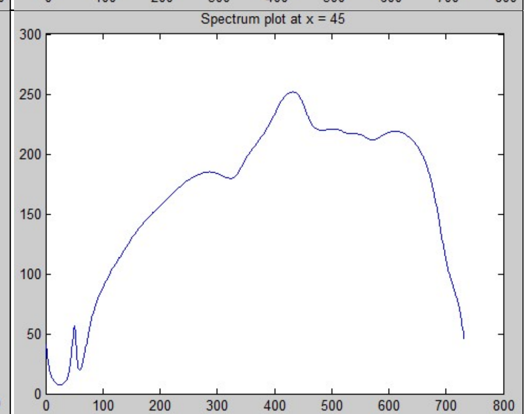
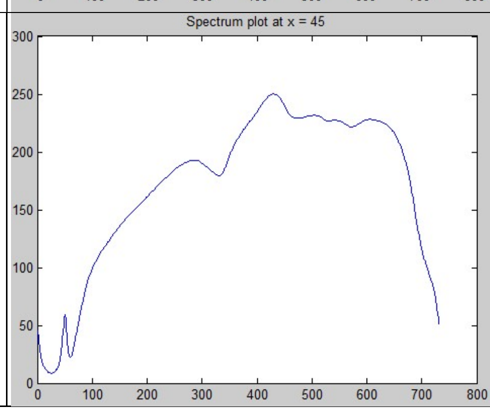
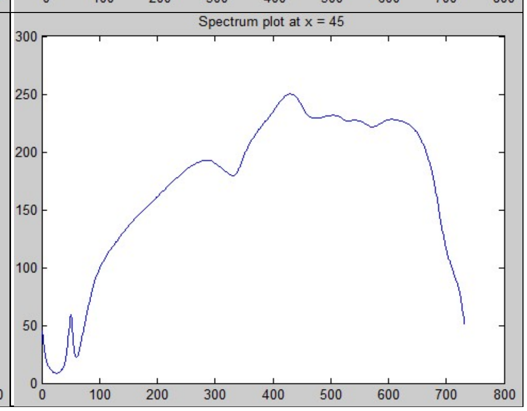
N	Sinusoidal	Saw-Tooth
3		
4		
5		

Fig 4.12 Comparison of Spectrum plot at face edge(x=45)

4.2.2 Triangular Prism

As in the mannequin head, experiment was repeated for triangular prism. Since the surface profile is simple in case of triangular prism, the output result were observed good for less number of shifted pattern as well.

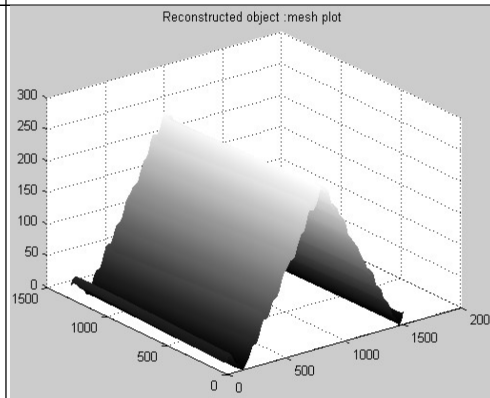
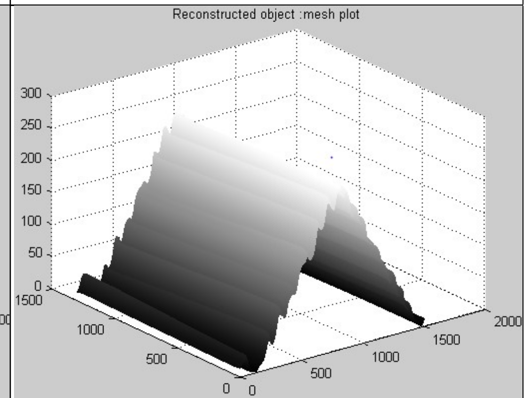
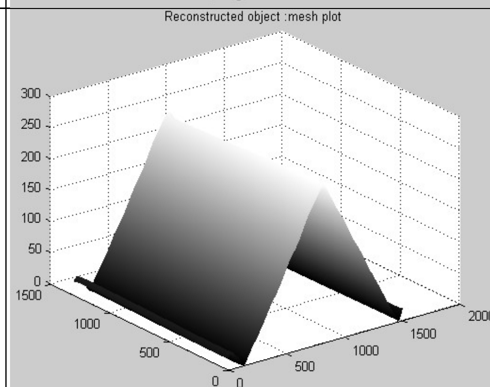
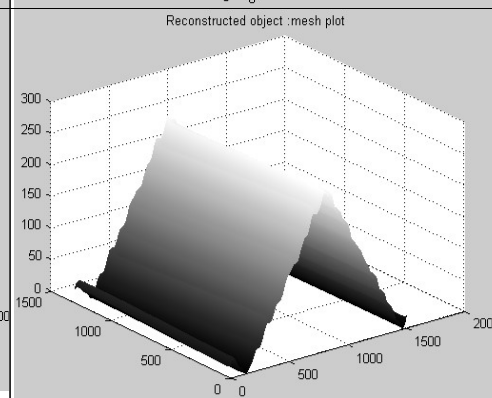
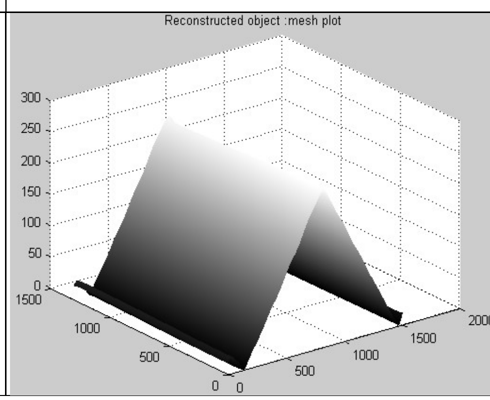
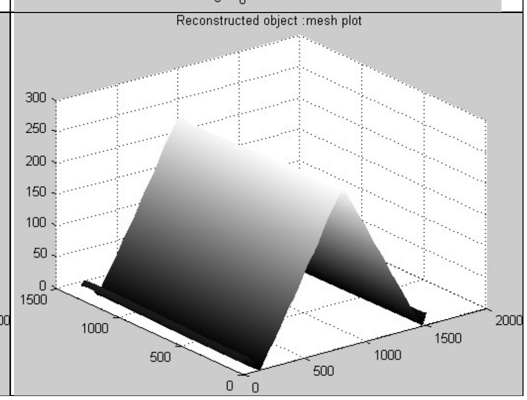
N	Sinusoidal	Saw-Tooth
3		
4		
5		

Fig 4.13 3D plot comparison for different number of phase shifted pattern

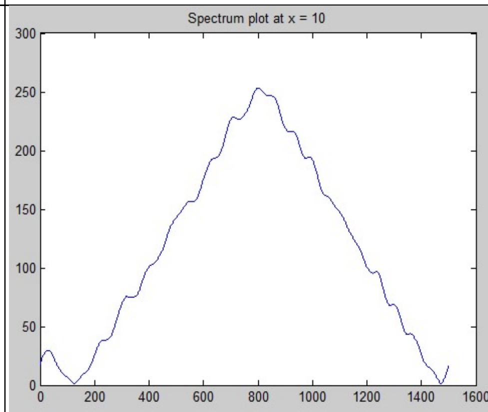
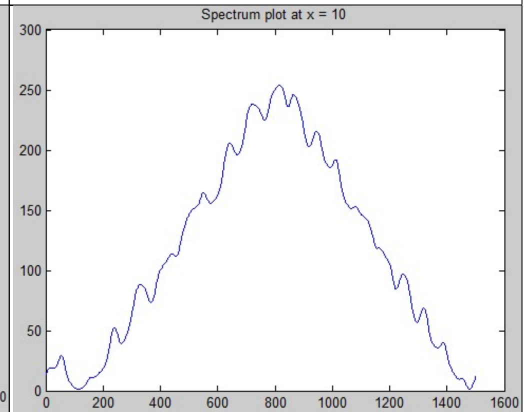
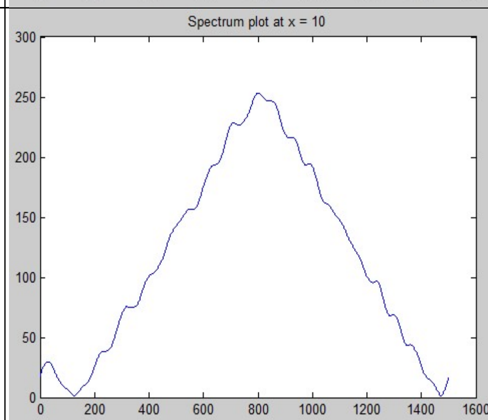
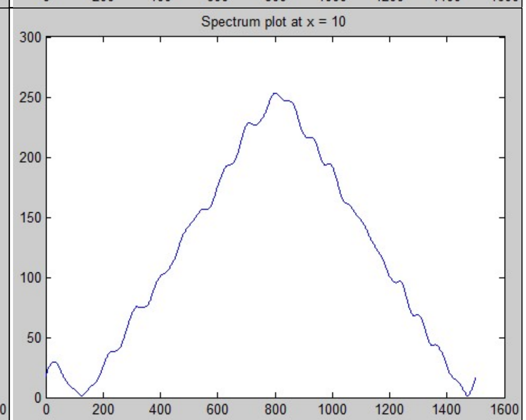
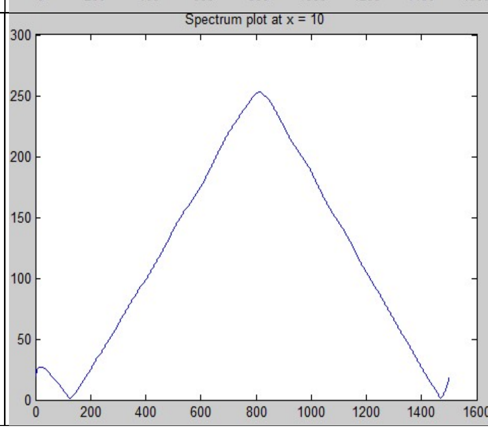
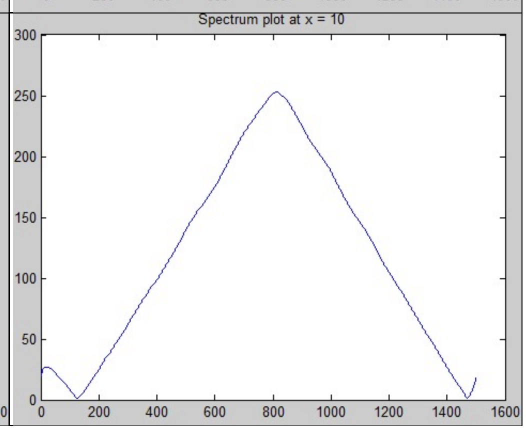
N	Sinusoidal	Saw-Tooth
3		
4		
5		

Fig 4.14 Comparison of Spectrum plot at face edge(y=10)

For Triangular Prism, the height information from reconstructed image for pixel position was mapped to the actual object height in that position by calculating it from object geometry. Considering calculated value as ground truth, error has been observed as follows:

N	Sinusoidal			Saw-tooth		
	Max Error(+)	Max Error(-)	MSE	Max Error(+)	Max Error(-)	MSE
3	1.345 mm	-0.678 mm	0.523mm	2.213 mm	-2.541mm	0.613mm
4	1.072 mm	-0.878 mm	0.323mm	1.231 mm	-1.504mm	0.393mm
5	1.022 mm	-0.881 mm	0.303mm	1.341 mm	-1.014mm	0.273mm

4.3 Discussion

Experiments were done for two objects; one with very simple surface profile with known geometry and another with complex surface profile taking different number of shifted patterns. From the experiment, more distortion in lower value of shifted pattern were observed for both fringe patterns while more effect was observed in saw-tooth pattern. In 5 shifted patterns, the response in both fringe patterns were similar. In 3 shifted pattern, for saw-tooth fringe, excessive distortion was observed that the shape of the object cannot even be recognized.

In this experiment, no any error correction technique is used. Primary goal of the experiment was to find the difference in effect of fringe pattern in reconstruction results in identical condition. So, there exists the error due to device gamma, occlusion, reflectivity of surface, stair effect etc. Due to the effect of device gamma, ideal sinusoidal patterns cannot be created and for low number pixel period the stair effect is introduced. This effect is more prominent in case of saw-tooth pattern since there is abrupt change in intensity at the end of period and start of next period. Beside that the response is better in linear slope of saw-tooth.

For the error calculation in Triangular Prism, the pixel position is mapped to real object surface co-ordinate value and height is compared. Though this technique is giving fair result for simple surface geometry but not possible for the complex surface profile. So, more accurate commercial device needs to be deployed to collect 3D point cloud as the ground truth.

CHAPTER 5: CONCLUSION

5.1 Conclusion

From the experiment on two objects Triangular Prism and dummy Mannequin Head, different results were obtained. Qualitative analysis has been done on effect of two fringe patterns on 3D reconstruction. It shows that for 5 shifted pattern or higher distortion is comparable for both. But for less number of shifted pattern distortion is more prominent in saw-tooth pattern. In the saw-tooth pattern, stair effect is found as primary cause of distortion.

5.2 Limitation

Mean square error is calculated mapping the pixel co-ordinate to the surface profile. So, it cannot be implemented in object with complex surface profile like mannequin head. It is basically the qualitative analysis. For more accurate fact and figure sensor device like laser scanner, structure sensor etc. needs to be deployed.

The experiment is done with single set of camera and projector. For actual 360 view rotating platform or multiple sets of camera and projector can be deployed.

5.3 Recommendations

In this thesis work, the comparative study is done on only two fringe pattern. These experiment can be further extended for number of other pattern being used.

And the more accurate quantitative analysis can be done deploying proper sensing device and stable 360 view platform.

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