



# **Three Step Fringe Projection for Breast Height Profile Imaging through Phase Shift Variation**

by

**Ahmad Syahir bin Ahmad Bakhit  
(1532521611)**

A dissertation submitted in partial fulfillment of the requirements for the  
degree of  
Master of Science (Microelectronics System Design Engineering)

**Faculty of Electronic Engineering Technology  
UNIVERSITI MALAYSIA PERLIS**

2021

## ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful, Alhamdulillah, after a long journey, all praises to Allah for the strengths and His blessing in completing this dissertation. Special appreciation goes to my supervisor, Dr Wan Mokhdzani bin Wan Nor Haimi, for his excellent supervision and constant support till the end. His invaluable help of constructive comments and suggestions throughout the experimental and dissertation works have contributed to the success of this research after such an extreme journey. Not forgotten, my appreciation to my ex-supervisor, Assoc Prof Dr Vityacharan a/l Retnasamy and his student Dr Rajendran a/l Vairavan for their endless support and knowledge regarding this topic especially in research experiment.

I would like to express my appreciation to all the related staff of School of Microelectronics Engineering now known as Faculty of Electronics Engineering Technology for their support and help towards my postgraduate affairs. My acknowledgement also goes to all my friends and colleagues for their co-operations. Last but not least, my deepest gratitude goes to my beloved parents and wife; Mr Ahmad Bakhit bin Mohd Taib, Mrs Maimunah bt Jamaluddin and Mrs. Shanise bt Rashid for their endless love, care, prayers and encouragement. They provide all the necessary financial support in order to finish up this project. In all adversaries, they are the cornerstone for me to fall back on, and I really thank them from the deepest of my hearts. Not to forget for those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION OF THESIS</b>	<b>i</b>
<b>ACKNOWLEDGEMENT</b>	<b>ii</b>
<b>TABLE OF CONTENTS</b>	<b>iii</b>
<b>LIST OF TABLES</b>	<b>vi</b>
<b>LIST OF FIGURES</b>	<b>vii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>x</b>
<b>LIST OF SYMBOLS</b>	<b>xi</b>
<b>ABSTRAK</b>	<b>xii</b>
<b>ABSTRACT</b>	<b>xiii</b>
<b>CHAPTER 1 : INTRODUCTION</b>	<b>14</b>
1.1 Introduction	14
1.2 Problem Statement	16
1.3 Objectives	17
1.4 Scope	18
1.5 Dissertation Organization	19
<b>CHAPTER 2 : LITERATURE REVIEW</b>	<b>20</b>
2.1 Introduction	20
2.2 Measurement Method	20
2.2.1 Contact Method	21
2.3 Non-Contact Method	23

2.4	Light Interference Phenomenon	23
2.4.1	Phase Shifting Interferometry	27
2.5	Fringe Patterns	28
2.6	Fringe Pattern Analysis Methods	31
2.6.1	Spatial Fringe	32
2.6.2	Fourier Transform Profilometry (FTP)	34
2.7	Breast Cancer Stages	36
2.8	Method of Breast Imaging	38
2.9	Digital Fringe Projection	40
2.9.1	Digital Fringe Projection Theory	40
2.9.2	Digital Fringe Projection Application	46
2.9.2.1	Digital fringe projection for surface metrology and medical applications	46
2.9.2.2	Optical breast imaging	50
2.9.2.3	Digital fringe projection for breast imaging	52
2.10	Chapter summary	56
	<b>CHAPTER 3 : METHODOLOGY</b>	<b>57</b>
3.1	Introduction	57
3.1.1	Digital Fringe Projection System	58
3.1.2	Fringe Pattern Generation	60
3.2	Phantom Breast Dimension	63
3.3	Depth of Field	63
3.4	Camera Aperture Settings	65
3.5	Fringe Projection for Height Map Analysis	66
3.6	Chapter Summary	68
	<b>CHAPTER 4 : RESULTS AND DISCUSSION</b>	<b>69</b>

4.1	Introduction	69
4.2	Camera Aperture Calibration	69
4.3	Phase Mapping and Phase Unwrapping Process Results of the Round Phantom Breast	73
4.3.1	Breast Height Profile Validation with Direct Measurement	82
4.4	Comparison of phase shift variance with previous Breast Surface Fringe Projection Imaging	86
4.5	Chapter Summary	87
	<b>CHAPTER 5: CONCLUSION</b>	<b>88</b>
5.1	Conclusion	88
5.2	Future work	89
	<b>REFERENCES</b>	<b>90</b>
	<b>APPENDIX A Derivation of 3 Step Fringe Projection Equation</b>	<b>100</b>
	<b>APPENDIX B Specifications of Projector Panasonic PT-LW80NTEA &amp; CCD Camera Avt Marlin F-146C</b>	<b>102</b>
	<b>APPENDIX C Standard deviation of breast height profile</b>	<b>104</b>
	<b>APPENDIX E Phase Shift Programs for 3 Step Fringe Projection</b>	<b>105</b>

## LIST OF TABLES

	<b>PAGE</b>	
Table 2.1	Brief comparison of the common fringe pattern generations methods	31
Table 2.2	The stages of breast cancer	37
Table 2.3	Comparison between breast cancer detection method	39
Table 2.4	Summary of fringe projection applications	55
Table 3.1	Summary of fringe projection applications	60
Table 3.2	Dimension of round breast	63
Table 4.1	Fringe visibility of fringe patterns at varied camera apertures	73
Table 4.2	Height map of round breast at phase shift of (a) $\pi/4$ (b) $\pi/2$ and (c) $2\pi/3$	81
Table 4.3	Standard deviation comparison between $\pi/4$ phase shift fringe projection method and digital caliper measurement of round breast	84
Table 4.4	Standard deviation comparison between $\pi/2$ phase shift fringe projection method and digital caliper measurement of round breast	84
Table 4.5	Standard deviation comparison between $2\pi/3$ phase shift fringe projection method and digital caliper measurement of round breast	85

## LIST OF FIGURES

		PAGE
Figure 2.1	The stylus instrument used to measure surface parameters	22
Figure 2.2	Cone-shaped stylus with key geometric features of tip radius and cone angle indicated.	23
Figure 2.3	Schematic illustration of constructive (top) and destructive (bottom) wave interference.	24
Figure 2.4	The VSI instrument used to measure surface parameters.	25
Figure 2.5	Schematic of a Mirau (left) and Michelson (right) interferometer – images Source: NPL web site ( <a href="http://www.npl.co.uk">http://www.npl.co.uk</a> ).	26
Figure 2.6	Illustration for the generation of fringe pattern using interferometry (Young’s experiment)	29
Figure 2.7	An example of a captured fringe distribution	33
Figure 2.8	(a) Frequency spectra of a typical deformed fringe image, with a simple rectangular filter $Hx, v$ shown by the red dashed line. (b) the filtered and frequency shifted spectrum. (c) Calculated phase.	36
Figure 2.9	Non-invasive method for breast cancer detection	38
Figure 2.10	Fringe projection profilometry system	40
Figure 2.11	Fringe projection geometry and image acquisition	41
Figure 2.12	The process of phase shift fringe projection	45
Figure 2.13	Three fringe shifted images (a-c) with addition of stair image (d) facial statue reconstruction	47

Figure 2.14	3D reconstruction process of (a) weld image (b) phase-shift pattern (c) wrapped image (d) 3D reconstruction	48
Figure 2.15	Height map of wound on patient hand	49
Figure 2.16	Finger phase map image (a-c), unwrapped phase map image	49
Figure 2.17	Set of four fringe images, each offset by $\pi/4$ phase, projected by a digitizer onto the back of a mannequin; the fifth image provided the surface texture	50
Figure 2.18	Breast contour analysis	51
Figure 2.19	Breast image with noise	52
Figure 2.20	Height profile imaging of Triangular shaped phantom breast	54
Figure 3.1	Process flow of breast surface analysis using fringe projection system	58
Figure 3.2	Digital fringe projection schematic setup	59
Figure 3.3	Actual setup for fringe projection system	60
Figure 3.4	Fringe pitch (P) variation selection (a) fringe pitch = 13 pixels (b) fringe pitch = 14 pixels (c) fringe pitch = 15 pixels	62
Figure 3.5	Depth of Field	64
Figure 3.6	Digital fringe projection experimental setup with phantom round breast	66
Figure 3.7	Steps of obtaining the height surface of round phantom breast	68
Figure 4.1	(a) f/1.4 fringe pattern image (b) f/1.4 line intensity plot	70
Figure 4.2	(a) f/5.6 fringe pattern image (b) f/5.6 line intensity plot	71
Figure 4.3	(a) f/16 fringe pattern image (b) f/16 line intensity plot	72

Figure 4.4	The image of wrapped phase map for a round phantom breast obtained from phase shift variance of (a) $\pi/4$ (b) $\pi/2$ and (c) $2\pi/3$	75
Figure 4.5	Image of unwrapped phase map of a round phantom breast obtained from phase shift of (a) $\pi/4$ (b) $\pi/2$ and (c) $2\pi/3$	77
Figure 4.6	The removal of carrier phase component from unwrapped phase map image of round phantom breast from the phase shift of (a) $\pi/4$ (b) $\pi/2$ and (c) $2\pi/3$	79
Figure 4.7	Cross section of reference line for round breast shape	82
Figure 4.8	Cross section height profile comparison of round breast with phase shift variance of $\pi/4$ , $\pi/2$ and $2\pi/3$	85
Figure 4.9	Maximum Standard Deviation comparison with previous work	86

## LIST OF ABBREVIATIONS

MRI	Magnetic Resonance Imaging
DWI	Diffusion Weighted Imaging
MBI	Molecular Breast Imaging
FV	Fringe Visibility
PET	Positron Emission Tomography
CT	Computed Tomography
SD	Standard Deviation
CCD	Couple Charge Device
LCD	Liquid Crystal Display

@This item is protected by original copyright

## LIST OF SYMBOLS

$I$	Fringe Intensity
$P$	Fringe Pitch
$\varphi$	Wrapped Phase
$\phi$	Phase angle
$\delta$	Angle phase shift
$\sigma$	Standard Deviation

@This item is protected by original copyright

## Unjuran Pinggiran Tiga Langkah untuk Pengimejan Profil Ketinggian Payudara melalui Variasi Anjakan Fasa

### ABSTRAK

Pengimejan payudara sangat memainkan peranan dalam kajian barah payudara serta pemantauan terhadap pesakit barah payudara. Pengesanan awal ketumbuhan payudara dapat membantu dalam kadar kelangsungan hidup pesakit barah dan secara tidak langsung dapat mencegah barah dari merebak ke bahagian tubuh atau organ yang lain. Kaedah terkini pengimejan melibatkan penggunaan mamogram, ultrasound dan MRI yang mungkin memudaratkan disebabkan hasil imbasan yang merbahaya. Oleh itu, kaedah pengimejan untuk mengenal pasti perubahan permukaan payudara menggunakan sumber pengimejan yang tidak berbahaya berdasarkan kaedah 3 langkah unjuran pinggiran yang perlu dihasilkan dan dioptimumkan. Dalam hasil kerja ini, sistem unjuran pinggiran digital dengan variasi perubahan tiga fasa dikembangkan untuk menghasilkan pengimejan payudara berbentuk bulat. Penyediaan sistem unjuran pinggiran terdiri daripada projektor digital, komputer dan kamera. Nilai kenaikan anjakan fasa yang digunakan dan dioptimumkan adalah  $\pi/4$ ,  $\pi/2$  dan  $2\pi/3$ . Kalibrasi penglihatan pinggiran sistem unjuran pinggiran 3 langkah berdasarkan tetapan bukaan kamera  $f/5.6$  dikalibrasi untuk meningkatkan beza jelas corak pinggiran semasa profil ketinggian payudara. Anjakan fasa diubah untuk menentukan anjakan fasa yang paling sesuai pada payudara berbentuk bulat berdasarkan tiga langkah unjuran pinggiran. Teknik *Phase Mapping* dan *Phase Unwrapping* dilakukan untuk mendapatkan ketinggian profil payudara berbentuk bulat dan dibandingkan dengan ukuran yang diperolehi dari angkup vernier digital. Hasil kajian menunjukkan bahawa anjakan fasa  $2\pi/3$  mempunyai imej profil ketinggian yang paling optimum dengan sisihan piawai kurang dari 0.08 cm berbanding ukuran menggunakan angkup vernier digital. Berdasarkan hasil yang diperolehi, anjakan fasa  $2\pi/3$  merupakan anjakan fasa yang paling sesuai digunakan dalam pengimejan payudara bulat apabila menggunakan kaedah 3 langkah unjuran pinggiran.

## Three Step Fringe Projection for Breast Height Profile Imaging through Phase Shift Variation

### ABSTRACT

Breast imaging is essential in the study of breast cancer diagnose as well as monitoring of breast cancer patients. Preliminary early detection of breast tumors may aid in the survival rates of cancer patients thus preventing the cancer from metastasizing to other body parts or organs. The current trend of breast imaging involves the usage of mammograms, breast ultrasound and MRI which may be harmful due its hazardous imaging sources. Therefore, an imaging method for identifying the breast surface changes using non-hazardous imaging sources based on the three-step fringe projection method is developed. In this work, a digital fringe projection system with three phase shift variances was developed to perform imaging of a round shaped phantom breast. The setup for fringe projection system consists of a digital projector, a computer and a camera. The value of phase shift increment that was experimented are  $\pi/4$ ,  $\pi/2$  and  $2\pi/3$ . The phase shift was varied to determine the appropriate phase shift on the round shaped breast based on the three-step fringe projection. The fringe visibility calibration of the three step fringe projection system based on the camera aperture settings of f/5.6 is calibrated to enhance the fringe pattern contrast during breast height profiling. Phase Mapping and Phase Unwrapping technique was applied to obtain the height profile of the round breast and was compared to measurements obtained from a digital vernier caliper. The results demonstrate that the  $2\pi/3$  had the most optimum height profile image with a standard deviation of less than 0.08 cm from the digital caliper measurements. Based on the results, the  $2\pi/3$  phase shift is most suited to be applied in the imaging of round breast when applying the three-step fringe projection.

## CHAPTER 1 : INTRODUCTION

### 1.1 Introduction

Fringe projection has been widely used and is of highly sought in the application of optical imaging. The reason for its widespread usage is because of the advances of light pattern projection originating from a structured light source. A variety of surface metrology applications utilizes the fringe projection method for surface profiling due to its ability to profile surfaces in a non-contact manner and its ability to generate height image profiles based on the surface topology. Some of the common surface metrology that applies fringe projection as its profiling method are the manufacturing, industrial and medical industries. A typical fringe projection system mainly consists of a projector as its source of structured light, camera for capturing the fringe pattern images on the surface to be profiled and a computer to process the image data for analysis. There are several fringe projection techniques that have been widely used which may vary on the type of imaging that is to be conducted whether the image to be extracted is stationary or mobile for multi shot fringe projection or single shot fringe projection respectively. The fringe projection to be conducted in this work is based on the multi shot or multiple fringe pattern images due to the stationary position of the surface to be measured. In the multi shot fringe projection techniques, various techniques have been previously employed namely the 3 step phase shift fringe projection, 4 step phase shift fringe projection, double 3 step phase fringe projection as well as the 5 step phase shift fringe projection method.

Most of the previous researchers have experimented with various phase shift increment including the  $\pi/4$ ,  $\pi/2$  and  $2\pi/3$ . In this work, the 3 step fringe projection is to be developed and applied for the surface profiling. Although previous researchers have utilized fringe projection as means of surface profiling, not a lot of them have optimized or experimented with the phase shift increment to enhance the obtained height image with minimal noise and intensity saturations. The 3 step phase shift was selected because of the minimum amount of steps involved to obtain the height images thus minimizing the amount of time required to obtain the fringe pattern image of the measured surface. A phase map is produced from the 3 step fringe projection whereby this is followed by an unwrapping process to obtain a height profile image.

In this study, the fringe projection is to be applied in the biomedical field. Previous applications of the fringe projection in the biomedical field include heart imaging, lesions imaging, back scoliosis injury detection, depth cuts on human body parts and more recently in the field of breast imaging which is to be conducted in this study. Breast imaging using fringe projection is still quite minimal whereby the height or 3D imaging of round phantom breast is to be carried out using the fringe projection system. The phase shift increment of the 3 step fringe projection is to be varied in order to optimize the height profile image obtained with less noise and image cut offs. The results obtained from this study may be used for future breast imaging research which can be applied in breast cancer effects of breast surface since investigations conducted on breast surface due to the presence of tumours is quite minimal.

## 1.2 Problem Statement

Women need early screening tests for early diagnosis. One of the most common symptoms of breast cancer is changes in the surface of the breast caused by tumours in the breast. Any types of breast surface changes need to be inspected for the possibility of an emerging tumour within the breast. Currently, several breast imaging modalities have been applied for breast imaging which are the mammogram, ultrasound, magnetic resonance imaging (MRI), computerized tomography (CT Scan) and several other methods. Most of these methods has their advantages and limitations whereby Mammograms require the X-ray technology and are known to produce false negative or false positive results while some methods require the injection of radio tracers which are harmful if done regularly and at a high dose (Hubbard et al., 2012).

In order to assist the current imaging methods of the female's breast with a non-invasive and non-hazardous imaging source, a fringe projection profilometry system is to be developed and optimized in terms of the phase shift variance. The fringe projection profilometry system applies a phase shifting technique to analyse the round phantom breast height profile (Gorthi & Rastogi, 2010a). Currently, not many researchers have experimented on different phase shift increments for the breast height profiles. With the investigation and optimization of the phase shift of the breast, further resemblance of the round breast is to be obtained from the 3 step fringe projection whereby assist future breast imaging studies with the presence of real tumours. The breast height profile in this study will be examined through the phase map and phase unwrapping technique to profile the breast height.

### 1.3 Objectives

The main purpose of this research is to develop and optimize the phase shift variance of a non-contact 3 step digital fringe projection profilometry on a round phantom breast surface for breast height profile imaging. In order to achieve the main goals, the following supplementary goals are defined:

- I. To develop a 3 step fringe projection system incorporating the projector, camera and computer as well as the fringe pattern generation for the phase shift increment of  $\pi/4$ ,  $\pi/2$  and  $2\pi/3$ .
- II. To enhance the fringe pattern contrast based on fringe visibility and camera aperture setting of the 3 step fringe projection system during breast height profiling.
- III. To analyse the round phantom breast based on the phase shift increment variance using the phase map and phase unwrapping technique for the 3 step fringe projection.

## 1.4 Scope

The main scope of this research is the development of the digital fringe projection system based on phase shift variance for a round shaped phantom breast height imaging. The experimental results of fringe analysis focused on the breast height variation obtained from the phase shift increment of  $\pi/4$ ,  $\pi/2$  and  $2\pi/3$ .

The scope of development for the fringe projection setup incorporates the fringe pattern generations, image acquisition with the CCD camera a projector for the projection of the non-collimated light. In this study, the generation of fringe patterns based on the 3 step phase shift technique is conducted using Microsoft Visual Studio software using C++ for the phase shift increment. Aperture calibration for experimenting with the fringe visibility or fringe contrast was performed for enhancing the round phantom breast height image.

The round phantom breast is analysed using fringe analysis. The fringe analysis mainly comprises of the phase map and phase unwrapping technique. The phase map image obtained from the fringe projection system is based on the three-step phase shift process. The main information within the phase map is then to be extracted with phase unwrapping method. The fringe analysis is performed using UU fringe optical metrology processing software. Therefore, the main scope of work in this study includes the 3 step fringe projection system, its calibration procedures incorporating the fringe pattern generation and fringe visibility and the height map profile of the round breast based on the quality guided phase unwrapping technique.

## 1.5 Dissertation Organization

This dissertation is organized into five chapters. **Chapter 1** describes a brief overview of fringe projection and its applications, the background review of breast cancer with their current imaging tools as well as highlighting the need for optimizing the 3 step fringe projection to aid in future breast imaging studies which may consist of breast tumours. The problem statement, research objectives and research scope of the study are also outlined in this chapter. **Chapter 2** discusses the background of breast shapes, breast cancer as well as the common breast imaging modalities for breast cancer screening. The concept of fringe projection as well as its applications in the biomedical field are also reviewed. The research methodology of this study is further elaborated in **Chapter 3** namely the fringe projection setup, the generation of fringe patterns based on the phase shift variance, fringe visibility calibration as well as the process involved in the phase shift fringe projection method. **Chapter 4** discusses the results obtained in this study which are mainly categorized into the images obtained from the phase map and phase unwrapping process as well as the height profile obtained from the round phantom breast. **Chapter 5** concludes the research conducted in this study through the achieved objectives and its contributions. This chapter also recommends and suggest potential future work to further enhance the research.

## CHAPTER 2 : LITERATURE REVIEW

### 2.1 Introduction

Nowadays, advances in screening and treatment have been proven to increase the survival rate of breast cancer patients. According to reports, there are reported 3.1 million cancer survivors in the United States. In Malaysia, according to the Malaysian National Cancer Registry Report (MNCRR), from 2012 to 2016, about 34 out of every 100,000 women were diagnosed with breast cancer compare from 2007 to mid-2011, it is just about 31 women among Malaysian (MNCR, 2019). It shows how the awareness lacking among Malaysian women back in early 2000s. Screening and awareness of breast cancer plays an important role in increasing the rate of cancer survival. The focus of this research is on the optimization of the 3 step fringe projection through the variation of the phase to aid in the imaging of a round shaped breast surface. Therefore, to design and optimize this breast imaging method, the background review of this study will incorporate to the parametric study such as measuring method, light interference phenomenon, fringe pattern and fringe pattern analysis method.

### 2.2 Measurement Method

There are two commonly used method of surface characterization which are a contact method of stylus profilometry and non-contact method of white light interferometry.

### 2.2.1 Contact Method

The contact profilometry uses a vertical stylus or probe for measuring surface variation as a function of position. Stylus-based instruments are the most common tools for measuring surface texture. A stylus profilometer works by tracing the surface with a sharp tip called stylus and recording the tip position using optical or electromechanical methods (Conroy et al., 2006). A stylus instrument contains a stylus that contacts the surface and an electromechanical transducer that converts its Z coordinate into voltage, followed by an amplifier that makes that voltage easier to digitize, followed by an analogue-to-digital converter that is connected to a computer (Gao et al., 2007). The tip of the stylus is usually made of diamond with a carefully calibrated profile. Because the stylus tip is a finite object, it cannot trace the surface perfectly and essentially gives a filtered image of the surface. For this reason, high frequencies in the surface profile would be more effected by the stylus shape than the low frequencies. The effect of the stylus force is also important which is if the force is too high, the surface may be damaged. If the force is too low, the stylus would not trace the surface with sufficient accuracy (Gao et al., 2007).

At the heart of the surface profilometer lies the stylus that makes direct contact with the surface under study. As the stylus is displaced across the surface, moving relatively at a constant speed, its vertical motion which is temporal displacement from a starting rest position is amplified via a transducer such as a coupled linear variable differential transformer (LVDT) or sensor and digitally converted for imaging and subsequent analysis by instrument software as shown in Figure 2.1 (Clark & Greivenkamp, 2002; Guo et al., 2013; D.-H. Lee & Cho, 2012; Morrison, 1995).

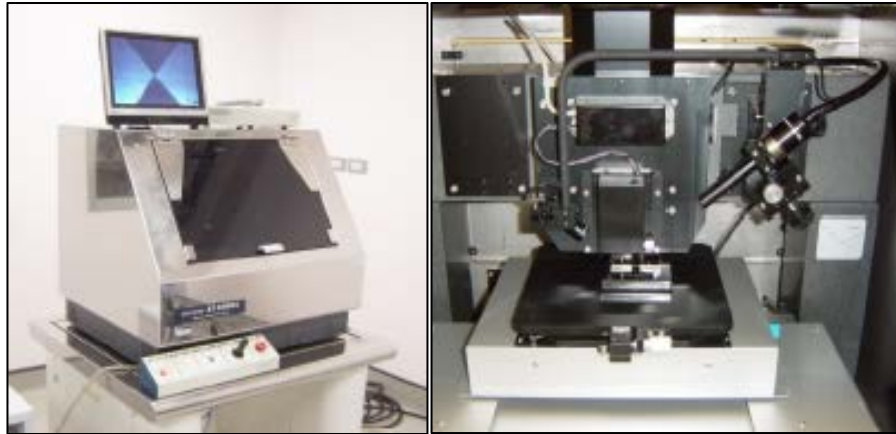


Figure 2.1 The stylus instrument used to measure surface parameters  
Source : (Guo et al., 2013)

Invariably, tested surfaces are 'hard' in nature for example, metals, alloys and ceramics that require the stylus to be composed of a robust, indestructible material which is most commonly diamond but other types, such as sapphire or ruby (both forms of aluminium oxide –  $\text{Al}_2\text{O}_3$ ), or in the case of 'softer' surfaces such as polymer, a silicon nitride ( $\text{Si}_3\text{N}_4$ ) tip, are often employed. Different stylus geometries and tip dimensions have been developed within the range of instruments currently commercially available for application in industrial settings or academic research laboratories. The most frequently deployed form of stylus has a conical shape with a rounded (contact) edge typically characterized by a cone angle of 60 degrees and a 2  $\mu\text{m}$  radius (D. Lee et al., 2012). This arrangement is shown schematically in Figure 2.2 below.

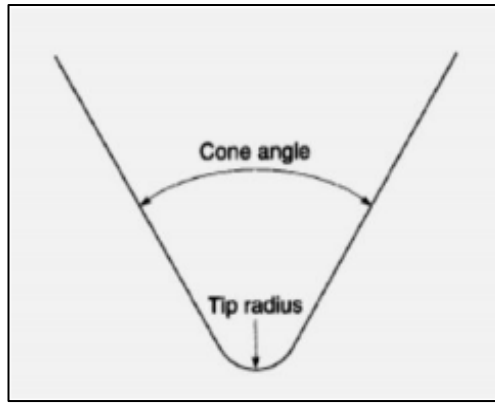


Figure 2.2 Cone-shaped stylus with key geometric features of tip radius and cone angle indicated.

Source : (Poon et al., 2001)(*Breast Anatomy / Articles / Mount Nittany Health System*, n.d.)

### 2.3 Non-Contact Method

The interferometric method of surface profiling uses the wave-like nature of light to accurately measure distances. The fundamental principle behind interferometric instruments goes back to Michelson and Morley (Michelson & Morley, 1887), who had observed a pattern of fringes after sending identical beams of light along slightly different paths.

### 2.4 Light Interference Phenomenon

The fundamental physical principle behind all optical interferometry methods and instrumentation is that of interference – the superposition of two electromagnetic waves that are either in-phase or out-of-phase. The in-phase superposition results in constructive interference whereby the resulting wave is enhanced in amplitude compared with each individual component, at the same time as out-of-phase superposition produces destructive interference resulting wave is diminished in amplitude compared with each

individual component as shown in Figure 2.3. When the result is viewed on a screen or through a microscope, a pattern of light and dark fringes is observed due to the constructive and destructive interference effects respectively (Sherrington et al., 1988.)

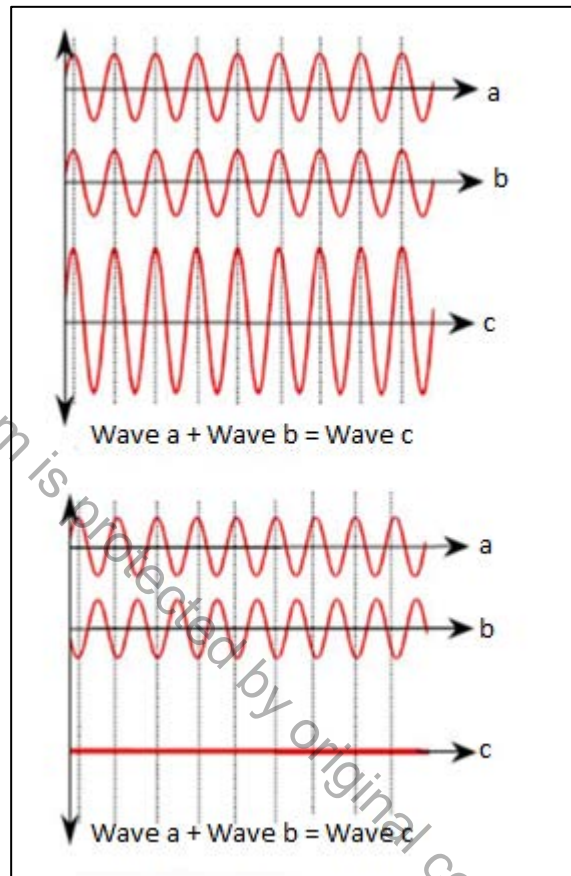


Figure 2.3 Schematic illustration of constructive (top) and destructive (bottom) wave interference.

Source : (Boonserm et al., 2011)

There are numbers of different optical configurations for specific interferometers, but the basic components of any such instrument as shown in Figure 2.4 include (Lehmann et al., 2014).

1. A light source, either monochromatic or broad-band;