NOVEL ALGORITHMS FOR PHASE EXTRACTION FROM ONE SINGLE SHEAROGRAPHIC FRINGE PATTERN AND THE RECOVERY OF OBSCURED DATA

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Novel Algorithms for Phase Extraction from One Single Shearographic Fringe Pattern and the Recovery of Obscured Data
單幅激光剪切散斑干涉條紋圖提取相位算法的研究及缺損數據的修復

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ABSTRACT

The invention of laser in 1960s creates a new realm for physicists and engineers. This new light source provides an ideal medium for coherent optics and incubates a series of new experimental techniques such as holographic interferometry and shearography. Since their invention, holographic interferometry and shearography have provided powerful experimental tools for the development of theoretical mechanics and applications in nondestructive testing.

In its early stage, shearography mainly provides qualitative measurement since shearographic fringe order can only be determined in integer level. With the rapid progress of computer technology and the advent of phase shifting technique in the 1980s, shearography gradually became a powerful tool for quantitative measurement with wide applications in both laboratory and industry. Accurate and robust as it is, the phase shifting technique requires capturing three or more fringe patterns at each deformed stage for phase determination, thus it is not suitable for dynamic measurement such as vibration, impact and fast deformation. To overcome this shortcoming, techniques based on Fourier transform or Wavelet transform which involve only one image are investigated and developed. However, such techniques always require generating a high frequency carrier fringe, which pose much difficulty in experiment design. Thus there is a great desire for a technique to extract shearographic phase information from one single fringe pattern.

In this thesis, a novel phase evaluation approach based on the idea of phase clustering has been developed to extract phase information from one single fringe pattern. Before the object begins to deform, four speckle images are captured and stored. After the object starts a non-repeatable deformation, only one single speckle image is captured for each deformed stage. With these five specklegrams, the background information, fringe modulation and initial random phase can be determined. Since the deformation induced phase change is a smooth phase map which owns the property of phase clustering, it is successfully extracted from one single deformed specklegram using the special clustering approach developed in this thesis.

A key step in applying the clustering approach for phase extraction is to guarantee the quality of the four speckle images captured before the deformation. These four images should be accurately phase shifted to ensure that the background information and fringe modulation are accurately obtained. Thus a proper calibration procedure of the phase shifter is proposed in this thesis, which helps to extract the deformation phase correctly.

Simulated results as well as a series of experiments conducted on continuously deforming specimens show the ability and robustness of the proposed clustering phase retrieval method. Comparison between the proposed method and standard four-step phase shifting method further confirms the accuracy of the proposed method.

The clustering phase retrieval method, however, may not work as well as phase shifting under some extreme cases such as very high fringe density or very noisy environment. This is because that the clustering approach utilizes only information from one deformed specklegram, while the phase shifting method has abundant information available from four deformed images. The result is that the clustering approach can work out a proper phase map for most of applications, but with some minor errors such as fringe interconnection and phase residues in some small areas for the extremely terrible situations. The fringe interconnection or phase residues may also happen when applying phase shifting method in very hostile environment. These erroneous data, which is called obscured data, will affect the phase unwrapping process and make it difficult to obtain the final unwrapped phase map for quantitative measurement.

To recover the obscured data, two effective methods have been proposed and investigated in this thesis. The first one is to correct the erroneous areas using a phase filtering method called phase reclustering filtering which is a nonlinear filter specially designed for wrapped phase filtering and performs better than normal filters. By use of the reclustering approach, most of the interconnected fringes are separated and phase residues are cleaned. Thus the wrapped phase map becomes workable with normal phase unwrapping algorithm. The other approach tends to cut out areas with erroneous wrapped phase information, and then unwrap the remaining correct wrapped phase. After that, the unavailable unwrapped phase in erroneous areas is reconstructed from the surrounding data by a computerized tomographic method developed in this thesis.

Simulated examples as well as a series of experiments conducted under extreme situations are used to verify the proposed phase reclustering filtering technique and the computerized tomographic phase reconstruction method. The results show that both methods are helpful. Compared with current filtering methods and reconstruction method, both proposed techniques have better performance.

The three methods developed in this thesis have together provided a complete solution for quantitative measurement of continuously deforming object. With further refinement and development, they may open a door for interferometric techniques to be widely applied for ultra high-speed measurement in both laboratory and industrial environment.

TABLE OF CONTENTS

ABSTRACT **i**

ACKNOWLEDGEMENTS **v**

TABLE OF CONTENTS **vi**

LIST OF FIGURES **ix**

LIST OF TABLES **xiv**

LIST OF SYMBOLS **xv**

CHAPTER ONE INTRODUCTION 1

1.1 Background 1

1.2 Phase Evaluation in Shearography 2

1.3 Objective and Scope 5

CHAPTER TWO LITERATURE REVIEW 7

2.1 History of Shearography 8

2.1.1 Conventional Shearography 8

2.1.2 TV Shearography 12

2.1.3 Digital Shearography 12

2.2. Typical Shearographic Setups 14

2.2.1 Michelson Image Shearing Interferometer 14

2.2.2 Wollaston Prism Based Shearographic Interferometer 16

2.3 Fringe Formation 18

2.3.1 Film Based Shearography 18

2.3.2 CCD Based Digital Shearography 20

2.4 Fringe Interpretation 21

2.5 Phase Measurement in Shearography 25

2.5.1 Fringe Tracking and Skeleton 26

2.5.2 Phase Shifting 26

2.5.3 Fourier Transform Method 31

2.5.4 Phase Unwrapping 33

2.6 Applications of Shearography 35

2.6.1 Surface Deformation, Strain and Curvature Measurement 35

2.6.2 Vibration Characterization 37

2.6.3 Nondestructive Testing 38

2.6.4 Residual Stress Measurement 41

2.6.5 Leakage Detection 42

CHAPTER THREE THEORETICAL DEVELOPMENT 44

3.1 Four-step Phase Shifting Method and Its Limitations 45

3.2 Clustering Approach for Phase Extraction from one Single Shearographic Fringe Pattern 49

3.3 Calibration of the Phase Shifter 54

3.4 Wrapped Phase Filtering using Phase Convolution and Reclustering Approach 61

3.5 Computerized Tomographic Technique for Obscured Phase Reconstruction 66

CHAPTER FOUR EXPERIMENTAL WORK 75

4.1 Walloston Based Shearographic Setups 75

4.2 Michelson Shearographic Setup 77

4.3 Concrete Properties Determination Using Shearography 79

4.4 Flash Light Shearography for Nondestructive Evaluation 80

CHAPTER FIVE RESULTS AND DISCUSSION 82

5.1 Clustering Phase Extraction from a Single Shearographic Fringe Pattern 82

5.1.1 Calibration of Shearography for Deformation Measurement 83

5.1.2 Simulation Verification of the Clustering Approach 85

5.1.3 Real Experiment Results with small and large shearing angle 88

5.1.4 Comparison of the Clustering Approach with Phase Shifting Technique 89

5.1.5 Concrete Deformation under Continuous Loading 92

5.1.6 Real time Deformation Determination of a Pressure Vessel 95

5.2 Phase Filtering using Reclustering Approach 97
5.3 Computerized Tomographic Phase Reconstruction Method 98
5.3.1 Simulated Results 99
5.3.2 Comparison with Current Interpolation Methods 102
5.3.3 Reconstruction of Obscured Shearographic Phase 111
5.3.4. Discussion on the Phase Reconstruction Method 116
CHAPTER SIX CONCLUSIONS AND FUTURE WORK 119
6.1 Conclusions 119
6.2 Future Work 120
BIBLIOGRAPHY 122
APPENDIX 141
A. LIST OF SELECTED PUBLICATIONS 141

LIST OF FIGURES

Figure 2.1 Conventional shearographic setup. 10

Figure 2.2 Shearographic fringe readout system. 11

Figure 2.3 A typical shearographic fringe pattern after optical Fourier filtering. 11

Figure 2.4 Optical layout for digital shearography. 13

Figure 2.5 Layout of digital shearography based on Michelson interferometer. 14

Figure 2.6 Layout of digital shearography based on a Wollaston Prism. 17

Figure 2.7 Typical fringe pattern from digital shearography. 18

Figure 2.8 Deformation diagram for digital shearography. 22

Figure 2.9 Schematic setup for in-plane strain measurement. 25

Figure 2.10 Illustration of the phase unwrapping process. 34

Figure 2.11 Three-dimensional plot of the surface deformation derivatives (a) $\partial w/\partial x$ and (b) $\partial w/\partial y$ of a central loaded plate obtained by shearography. 36

Figure 2.12 In-plane strain component of a cantilever beam; (a) result from shearography and (b) theoretical result. 36

Figure 2.13 Typical time-averaged shearography fringe pattern depicting the vibration amplitude derivative of a rectangular plate vibrating at its fundamental mode. 38

Figure 2.14 Internal cracks of a steel pipe line detected by thermal pulse shearography. 40

Figure 2.15 Bonding weakness of a composite-reinforced concrete structure detected by thermal pulse shearography. 40

Figure 2.16 Wrapped phase map depicting the residual stress level of an aluminum panel by the hole drilling method and shearography. 42

Figure 2.17 A leakage detected by shearography. 43

Figure 3.1 Speckle patterns before (a) and after (b) a deformation; the corresponding random phase obtained from Four-step phase shifting (c) and (d); and the final wrapped phase map ∆ representing the deformation field (e). 48

Fig. 3.2 The background intensity distribution before (a) and after (b) a deformation. 51

Figure 3.3 Demonstration of the phase values within an area of 3x3 pixels. 53

Figure 3.4 Layout of the plane polariscope for phase shifter calibration. 56

Figure 3.5 Plot of light intensity variation with applied voltage on 24 pixels. 58

Figure 3.6 Plot of average light intensity variation with applied voltage. 58

Figure 3.7 Wrapped phase change of the retarder with regard to applied voltage. 60

Figure 3.8 Unwrapped phase change of the retarder with regard to applied voltage. 60

Figure 3.9 A typical initial wrapped phase map with much speckle noise presents. 62

Figure 3.10 Typical wrapped phase after phase convolution filtering. 64

Figure 3.11 The effect of phase reclustering. 66

Figure 3.12 Extreme case when fringes are too dense in some area. 67

Figure 3.13 Schematic diagram of the tomographic technique for phase Reconstruction. 68

Figure 3.14 Discretization of Eq. (3.23) on a rectangular domain. 70

Figure 3.15 The unwrapped phase of Fig. 3.11 by cutting out the central part. 73

Figure 3.16 The unavailable central area are reconstructed using the proposed phase reconstruction method 73

Figure 3.17 Solution procedure using the proposed CTR method 74

Figure 4.1 Layout of shearography based on a Wollaston Prism and a Liquid Crystal variable wave retarder with large shearing angle. 76

Figure 4.2 A Michelson base shearographic setup. 78

Figure 4.3 Shearographic setup with large shearing angle for concrete testing. 79

Figure 4.4 Schematic setup of flash light shearography using Wollaston prism. 80

Figure 5.1 Shearographic fringe pattern showing the displacement derivative. 84

Figure 5.2 Comparison of theoretical and shearographic result. 85

Figure 5.3 (a) Wrapped phase obtained by the clustering phase extraction algorithm using simulated images;
(b) the corresponding unwrapped phase. 86

Figure 5.4 (a) Holographic wrapped phase obtained by the clustering phase extraction algorithm using simulated images;
(b) the corresponding unwrapped phase. 87

Figure 5.5 Typical shearographic fringe pattern of (a) a central loaded rectangular plate and (b) the corresponding wrapped phase obtained by the clustering approach. 88

Figure 5.6 Typical shearographic fringe pattern with large shearing angle of a central loaded square plate (a) and the corresponding wrapped phase map (b). 89

Figure 5.7 Wrapped phase obtained by standard four-step phase shifting. 90

Figure 5.8 Unwrapped phase map of the fully clamped square plate obtained by four step phase shifting (a) and the proposed clustering method (b). 90

Figure 5.9 Comparison of unwrapped phase from the clustering phase extraction method and four step phase shifting at the cross section. 91

Figure 5.10 Determination of out-of-plane displacement of concrete prism under concentrated load using shearography with large shearing angle. 92

Figure 5.11 Typical shearographic phases depicting the concrete deformation under continuous central loading, the deformed speckle images are captured in the sequence of (a), (b), (c) and (d). 93

Figure 5.12 Fringe pattern at four deformed stages. 96

Figure 5.13 Corresponding wrapped phase maps. 96

Figure 5.14 Wrapped phase map with quite a few erroneous phase. 97

Figure 5.15 Wrapped phase map after reclustering filtering showing that all the fringe interconnection area are filtered out. 98

Figure 5.16 (a) Simulated quadratic surface with data lost;
(b) Reconstruction result using the proposed computerized tomographic phase reconstruction method. 100

Figure 5.17 (a) Simulated saddle surface with data lost;
(b) Reconstruction result using the proposed computerized tomographic phase reconstruction method. 101

Figure 5.18 (a) A simulated surface composed of scaled and translated Gaussian distributions;
(b) the cracked surface for reconstruction;
(c) the reconstructed results using bicubic interpolation;
(d) the reconstructed results using nearest interpolation;
(e) the reconstructed results using biharmonic interpolation;
(f) the reconstructed results using the CTR method. 105

Figure 5.19 (a) An experimental phase map of a human back;
(b) the cracked surface for reconstruction;
(c) the reconstructed results using bicubic interpolation;
(d) the reconstructed results using nearest interpolation;
(e) the reconstructed results using biharmonic interpolation;
(f) the reconstructed results using the CTR method;
(g) 3D plot of reconstruction result of (e);
(h) 3D plot of reconstruction result of (f). 110

Figure 5.20 (a) A shearographic phase map of a central loaded plate

with lost data;
(b) The reconstruction result by the tomographic method;
(c) A 3-D plot of the reconstructed phase map. 113

Figure 5.21 (a) A shearographic wrapped phase map with cracked data;
(b) the unwrapped phase map with cracked data;
(c) the reconstruction result by the proposed tomographic method. 115

Figure 5.22 (a) An unwrapped phase map with some data lost due to lighting saturation;
(b) The reconstruction result. 116

Figure 5.23 Two surface with exactly the same boundary data.
(a) Reconstructed from the CTR method and
(b) original simulated data. 118

LIST OF TABLES

Table 2.1 List of Common Phase Shifting Algorithms. 31

Table 5.1 Dimensions and Mechanical Properties of the Disk Specimen. 84

Table 5.2. Concrete modulus of elasticity obtained by different methods. 94

LIST OF SYMBOLS

a	The amplitude of laser wavefront
A	Complex wavefront
e	Base of logarithm
φ	Phase of laser wavefront
A_c	The wavefront after shearographic interference
δx	Shearing distance
I	Intensity of the speckle image before deformation
ϕ	Random phase after shearographic interference
I'	Intensity of the speckle image after deformation
Δ	Phase difference due to a deformation
δ	Infinitesimal increment in displacements or coordinates
λ	Wavelength of the laser source
$\frac{\partial u}{\partial x}$	Partial displacement derivative in x direction
π	Circular constant
α	Angle between the illumination direction and the yz plane
β	Angle between the illumination direction and the xz plane
γ	Angle between the illumination direction and the $z-axis$
I_i	Image intensity of the i^{th} phase shifted image
δ_i	The i^{th} phase shift amount

E	Error function
f	Frequency of the light wave
b	Background intensity
x_c	Clustering center
$\delta(v)$	Retardation imposed by voltage v
θ	Angle between the retarder slow axis and $x-axis$
k	Constant
$d(x,y)$	Specially defined distance function
$\mathrm{Im}[\ ]$	Imaginary part of a complex number
$\mathrm{Re}[\ ]$	Real part of a complex number
(x,y,z)	Spatial coordinate
(u,v,w)	Three-dimensional displacement

SUBSCRIPTS

1, 2, …	Identifiers

SUPERSCRIPTS

$*$	Conjugate