Dissertation Abstract

Report no.	(Course-based) Mathematics, Electronics and Informatics No.1123	Name	TRUONG CONG TUAN
Dissertation title	**Study of 2D single-shot optical interferometry for high-speed surface profilometry** 高速物体表面形状計測のための２次元シングルショット光干渉計の研究		

Abstract

Inspecting goods or products at the time of production is required to prevent defects in manufacturing process for quality assurance. It also increases the productivity because the inspection and manufacturing are simultaneously performance. Therefore, there is a huge demand to develop a real-time measurement system for the inline inspection, which required a high-speed volume measurement, μm order resolution in the range of ten mm order, non-destructive and non-contact, available to measure in variable environments, and strong for vibration. Several techniques include time of fly, confocal sensor, triangulations, laser interferometry, and low-coherence interferometry, are the candidate to meet the above requirements. However, resolution of time of fly has limitation of mm; measurement range of confocal sensor and laser interferometry are limited in hundred nm and mm, respectively; triangulation is restricted by blind region. Therefore, the low-coherence interferometry has become potential candidate for inline inspection in industry. The 2D single-shot imaging based on low-coherence interferometry has been introduced for industrial application. The axial measurement range of single interference order of a 2D image, achieved by 2D single-shot interferometry, was limited to a millimeter order, due to the restrictions of the total pixel number of the 2D image sensor (thousand pixels) and the axial resolution (micrometers order). To extend the axial measurement range of 2D single-shot interferometry, the incoherent optical frequency comb (OFC), which had hundreds GHz free spectral range (FSR) to match with a millimeter axial range of single 2D image, was proposed. However, the incoherent OFC, which generated by placing an Fabry-Perot etalon after broadband light source, suffered from energy loss causing low sensitivity in the 2D single-shot system.

Hence, in this research, we develop a pseudo OFC interferometry to expand the axial measurement range and to increase the usage energy efficiency of 2-D single-shot interferometry. The pseudo OFC interferometry is realized by a discrete frequency swept laser. In which, the frequency is oscillated in frequency-domain at hundreds gigahertz step and scanned in time-domain at nanosecond step. By setting the sweep repetition time is sufficient faster than shutter speed of CCD camera, the discrete frequency swept laser can be utilized for 2D single-shot pseudo comb interferometry for expanding the axial measurement range. At each instant, as the entire source energy is concentrated in one comb line, the generated pseudo OFC interferometry has high energy efficiency for metrology, compared to the conventional incoherent OFC.

In additionally, we also proposed the axial zoomable 2-D single-shot interferometry to vary the axial measurement and to increase usage energy efficiency of conventional 2-D single-shot interferometry. In which, the etalon is omitted, the Spatial Phase Modulator (SPM) is utilized for tuning the measurement range of 2D single-shot system. Thus, the resolution is improved by hundreds nm bandwidth in visible region of SC light source.

From the explanation of the research background, the thesis's objective issues:

Expand the axial measurement range and increase the energy usage efficiency of the conventional 2D single-shot interferometry.

From the research objective, we create the research chart as follow:

- Zoomable axial measurement range and increase the usage energy efficiency of 2D single-shot interferometry by using SPM.
- Expand the axial measurement range and enhance the energy efficiency of 2D single-shot interferometry by developing a discrete frequency swept laser for a pseudo OFC interferometry

Therefore, the thesis is classified into 5 chapter:

Chapter1 – General Introduction: this chapter mention the requirement of inline inspection for industrial, which is target of this research. From these requirements, several candidate technics are listed to make the comparison. Accordingly, the low-coherence is pointed out as a potential candidate to meet al requirements. The low-coherence interferometry in time-domain and frequency-domain, are introduced as a background of this research. The of 2-D single-shot system, which base on the time-domain low-coherence interferometry and already developed by our group, is introduced. The remained problems of the conventional 2-D single-shot to the motivation of the thesis are presented. Finally, research objective and the outline of the thesis will be also briefly described.

Chapter 2– Development of 2D zooming single-shot imaging: the axial zoomable 2-D single-shot interferometry is proposed to vary the axial measurement range as well as improve usage energy efficiency of conventional 2-D single-shot interferometry. Theory of grating (SPM) leads to the operation principle and optical setup of system is presented. Several experiments were performed to show the efficiency of proposed system: the measurement range of 2-D single-shot system can be changing from approximate 200 μm to 3500 μm, the tomography resolution is achieved at approximate 2.5 μm, the energy efficiency of grating (SPM) is mentioned to comparison to the energy loss of etalon of previous report. A flexibility of the 2-D zooming single-shot interferometry is also demonstrated for profilometry and tomography of coin sample, multi gauge block, and multilayer-glass sample, respectively.

Chapter 3 – Realize a convenience type of pseudo optical frequency comb interferometry by a discrete frequency swept laser: this chapter shows the development of discrete frequency swept laser. The cavity of the proposed light source consists of semiconductor amplifier as a lasing medium, a frequency tuning part is combination of polygon mirror scanner and grating, and a frequency step controller. In which, the frequency is oscillated at hundreds gigahertz step in frequency-domain and scanned at nanosecond step in time-domain. The sweep repetition rate (SRR) is achieved at approximate 29 kHz corresponds to the sweep repetition time of approximate 34 μs. Therefore, the discrete frequency swept laser can be utilized for 2D single-shot pseudo comb interferometry, where shutter speed of CCD camera is typically controlled at 10 μs second order. At each instant, as the entire source energy is concentrated in one comb line, the generated pseudo comb has high energy efficiency for metrology, compared to the conventional OFC, where the energy is separated in several comb lines or longitudinal frequency modes. The intensity pseudo comb peak and average power is 12dB and 9 dB higher than that of filtered-comb of conventional 2-D single-shot system, respectively. The proposed light source with the frequency step of approximate 200 GHz and the SRR of 29 kHz is demonstrated, showing an effectiveness for the axial range expansion of 2D single-shot industrial profilometry and tomography in several tens millimeters.

A crystal $KTa_{1-x}Nb_xO_3$ (KTN) optical beam scanner is also mentioned to improve the SRR of a convenience type of discrete frequency swept laser. Instead of 29 kHz of SRR of polygon scanner, 100 kHz sweep repetition rate of discrete frequency swept laser is achieved by KTN scanner.

Chapter 4 – High power pseudo optical frequency comb interferometry: In this chapter a new approach of lasing medium and frequency scanner using Pr^{3+} doped to fiber and Acousto Optic Defector (AOD) are presented, respectively. The wavelength can be scanned within several nm (from 636 nm to 638 nm). The average power is measured at approximate 29 mW with stability of approximate ± 3%. The initial experimental results show the potential of these approach for generating high power pseudo comb. For the future work, the system's setup needs to be considered to expand the wavelength scanning range and enhance the average power of the system.

Chapter 5 – Conclusion and future work. A summary of my research work and the future work of pseudo comb light source are discussed.