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Effect of windowing on a sensing signal generated by self-mixing interferometry

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Abstract

Copyright 2019 SPIE. The laser diode (LD) is modulated by the injection current of triangular waveform and a photo diode (PD) is packaged in the rear of the LD. The laser reflected by the target re-enters the cavity of LD and contains the target's displacement information. The information is carried within the laser intensity and can be pickup by the PD. We call this laser intensity as self-mixing interferometry (SMI) signal. While processing the sensing SMI signals, we should carefully determine the windowing function and reduce the effect of windowing in the FFT and IFFT process while applying the mathematical model. Simulation results show that the proposed design is able to accomplish the measurement of micro-displacement with high resolution and great accuracy.

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Effect of windowing on a sensing signal generated by self-mixing interferometry

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Abstract

The laser diode (LD) is modulated by the injection current of triangular waveform and a photo diode (PD) is packaged in the rear of the LD. The laser reflected by the target re-enters the cavity of LD and contains the target's displacement information. The information is carried within the laser intensity and can be pickup by the PD. We call this laser intensity as self-mixing interferometry (SMI) signal. While processing the sensing SMI signals, we should carefully determine the windowing function and reduce the effect of windowing in the FFT and IFFT process while applying the mathematical model. Simulation results show that the proposed design is able to accomplish the measurement of micro-displacement with high resolution and great accuracy.

Keywords: laser diode, sensing signal, self-mixing interferometry, windowing effect, micro-displacement

I Introduction

When a fraction of optical feedback created by external cavity (or target) re-enters the internal cavity of a laser diode (LD), the laser intensity and optical frequency will then be altered. The modulated laser intensity is called as a self-mixing interferometry (SMI) signal. The SMI signal carries the information of the parameters related to the LD and its external cavity. Over the years, various SMI-based sensing applications have been reported, including the measurement of velocity, vibration, displacement, and laser related parameters [1-5]. Recently, SMI-based sensing has been extended for material parameter measurement, acoustic detection and biomedical applications etc. [6, 7]. When the injection current of the LD is modulated by a periodic triangular waveform, the phase of the detected SMI signal contains the micro-displacement of the external target. A basic configuration of an SMI system with modulated injection current is depicted in Fig. 1, which consists of an LD, a photodiode (PD) packaged in the rear of the LD, a lens and an external moving target. The injection current of the LD will be modulated by the triangular wave that is generated from a signal generator.

Figure 1. Schematic SMI system for micro-displacement sensing.

The laser intensity $I(t)$ received by PD and target's displacement $d(t)$ can be expressed as below [8]:

$$I(t) = A(t) + B \cos \Phi(t) \approx A(t) + B \cos(2\pi f_c t + \phi_0 + \phi(t)), \quad (1)$$

$$d(t) = \frac{\lambda}{4\pi} \times \phi(t), \quad (2)$$

where $A(t)$ is the intensity of modulated triangular signal, B is the amplitude of SMI signal, $\Phi(t)$ is the phase of SMI signal, f_c is the carrier frequency, ϕ_0 is the reference phase

of fixed target, $\phi(t)$ is the phase linked to micro-displacement and λ is the laser wavelength. The micro-displacement can be set as $d(t) = d_0 \cos(2\pi f_d t)$, where d_0 is the amplitude of displacement and f_d is the frequency of displacement. By applying Fast Fourier Transform (FFT) on $B \cos \Phi(t)$, the phase $\phi(t)$ corresponds to the displacement in each rising/falling part of the triangular period can be obtained. However, to achieve more accurate measurement by using this method, a large number of fringes in each triangular period is needed and the target needs a low moving velocity. To lift the limit of this method, we developed an algorithm by using a reference signal to retrieve the displacement [9]. We denote the laser intensity with a fixed target after removing the modulation triangular signal as:

$$I_{FIX-T}(t) = B_1 \cos(2\pi f_c t + \phi_0), \quad (3)$$

and the laser intensity with a moving target after removing the modulation triangular signal as:

$$I_{MOV-T}(t) = B_2 \cos(2\pi f_c t + \phi_0 + \phi(t)), \quad (4)$$

where B_1 and B_2 are the signal amplitudes. By applying FFT and IFFT on Equation (3) and (4), we have:

$$d(t) = \frac{\lambda}{4\pi} \times \frac{\text{imag}(\text{IFFT}(I_{MOV-T}(f)) \times [\text{IFFT}(I_{FIX-T}(f))]^*)}{\text{real}(\text{IFFT}(I_{MOV-T}(f)) \times [\text{IFFT}(I_{FIX-T}(f))]^*)}. \quad (5)$$

This algorithm achieves the micro-displacement measurement without any adjustments of the system and lifted the restriction on the velocity of the target. However, a new issue has raised when applying FFT and IFFT. The effect of windowing in this process will introduce error while retrieving the micro-displacement. This paper compared the performance of three different window functions while applying them to the SMI signal. The result shows that the Nuttall window edges over others as it has the minimal displacement error.

II Reducing the effect of windowing

We studied the effect of windowing when taking FFT and IFFT processing for the demodulated signal $I_{FIX-T}(t)$ and

$I_{MOV-T}(t)$. When applying windowing function, the main lobe width of its spectrum should be as narrow as possible to obtain high frequency resolution; the side lobe attenuation should be as large as possible to reduce spectrum tailing. We tested three different window functions (rectangular, Hamming and Nuttall window) and made a displacement error comparison to show the performance of each window function.

In the simulation, the target displacement is set as $d(t) = 150 \cos(2\pi \times 2 \times t) \text{ nm}$. The frequency of modulated triangular current is 20 Hz , this corresponds to a 0.025 s of window length, as shown in Fig. 2 and highlighted by the red box. In this sensing system, there are 5 SMI fringes in each window.

Fig. 2. (a) target displacement; (b) Intensity corresponds to the triangular modulation; (c) Laser intensity with a fixed target after removing the modulation; (d) Laser intensity with a moving target after removing the modulation.

Fig. 3 shows the comparison of original and retrieving displacement in this window. The effect of windowing can cause large displacement error at the beginning and end part

within each window section. By using a Nuttall window, the displacement error can be reduced to $error_{MAX} / d_0 = 1.3\%$, while rectangular window is 2.6% and Hamming window is 2.31%. Most part of the retrieving displacement with a Nuttall window is more accurate than other two window functions, as the displacement error comparison shown in Fig. 4.

Fig. 3. Comparison of original and retrieving micro-displacement with different windows.

Fig. 4. Comparison of displacement error.

III Conclusion

In this work, we proposed an algorithm for micro-displacement measurement and studied the effect of windowing when applying FFT on SMI sensing signals. The simulation results show that using a Nuttall window with 0.025s window length has the best performance comparing to Rectangular and Hamming window and it can achieve a precise micro-displacement measurement.

References

- [1] Donati, S., Giuliani, G., and Merlo, S., "Laser diode feedback interferometer for measurement of displacements without ambiguity," *IEEE Journal of Quantum Electronics*, 31(1), 113-119 (1995).
- [2] Yu, Y., Xi, J., and Chicharo, J. F., "Measuring the feedback parameter of a semiconductor laser with external optical feedback," *Optics Express*, 19(10), 9582-9593 (2011).
- [3] Fan, Y., Yu, Y., Xi, J., and Chicharo, J. F., "Improving the measurement performance for a self-mixing interferometry-based displacement sensing system," *Applied Optics*, 50(26), 5064-5072 (2011).
- [4] Ruan, Y., Liu, B., Yu, Y., Xi, J., Guo, Q., and Tong, J., "Measuring Linewidth Enhancement Factor by Relaxation Oscillation Frequency in a Laser with Optical Feedback," *Sensors*, 18(11), 4004 (2018).
- [5] Taimre, T., Nikolić, M., Bertling, K., Lim, Y. L., Bosch, T., and Rakić, A. D., "Laser feedback interferometry: a tutorial on the self-mixing effect for coherent sensing," *Advances in Optics and Photonics*, 7(3), 570-631 (2015).
- [6] Lin, K., Yu, Y., Xi, J., Li, H., Guo, Q., Tong, J., and Su, L., "A Fiber-Coupled Self-Mixing Laser Diode for the Measurement of Young's Modulus," *Sensors (Basel, Switzerland)*, 16(6), 928 (2016).
- [7] Liu, B., Ruan, Y., Yu, Y., Xi, J., Guo, Q., Tong, J., and Rajan, G., "Laser Self-Mixing Fiber Bragg Grating Sensor for Acoustic Emission Measurement," *Sensors*, 18(6), 1956 (2018).
- [8] Wang, M., "Fourier transform method for self-mixing interference signal analysis," *Optics & Laser Technology*, 33(6), 409-416 (2001).
- [9] Wang, H., Yu, Y., Xi, J., Guo, Q., and Tong, J., "A Self-Mixing Laser Diode for Micro-Displacement Measurement." *IEEE International Frequency Control Symposium* (2018).