Implementation of Phase Generated Carrier Technique for FBG Laser Sensor Multiplexed System Based on Compact RIO

Lei Feng, Jun He, Jing-Yuan Duan, Fang Li, and Yu-Liang Liu

Abstract—This paper presents the fundamental technique of phase generated carrier (PGC) and its realization on compact reconfigurable input and output (RIO) which adopts real-time and field programmable gate array (FPGA) techniques. Improvement of the PGC technique is also introduced by using peak-to-peak value detection method to reduce the influence of variation of the light intensity. A four-element fibre Bragg gratings (FBG) laser sensor system is conducted in the experiment and the demodulated results demonstrate correlation coefficient as high as 0.995 with the reference signal and the dynamic range to be 120dB@63Hz.

Index Terms—Compact reconfigurable input and output (RIO), demodulation, fibre Bragg gratings (FBG) laser sensor multiplexed system, phase generated carrier (PGC).

1. Introduction

With the development of optics fiber sensor techniques, fibre Bragg gratings (FBG) laser sensors have attracted considerable attention because of the high sensitivity and easiness to be multiplexed along a single fibre[1][2]. FBG laser sensors can be multiplexed with different multiplexing technology such as wavelength division multiplex (WDM)[3][4], time division multiplex (TDM), and so on. To achieve a FBG laser sensor system with high performance, a proper demodulation algorithm is also needed. Among various demodulation algorithms adopted in optics fibre sensor system, it can be seen that phase generated carrier (PGC) technique has been widely used because this method prevents the fade of sensitivity by introducing large amplitude of carrier and the demodulated results also demonstrate high resolution through numerous experiments[6]. However, because this technique needs relatively complex calculations[7], it requires demodulation system with high performance to carry out this algorithm in a real-time manner especially when it comes to the multiplexed optics fiber sensor system that employs WDM structure since this structure requires the demodulation system to simultaneously implement PGC techniques on different channels. With great amount of calculations within short time, it is hard to realize whole demodulation method on the computer which can not provide a reliable and steady performance. Compact reconfigurable input and output (RIO), however, can provide the engineers a convenient and stable way to realize those calculations on the embedded system because compact RIO adopts real-time and field programmable gate array (FPGA) techniques which can be explored by the graphical software—LabVIEW. Besides, as compact RIO could be explored in a relatively short period with LabVIEW, the scientists and the engineers can use the saved time and energy to focus on other aspects of the system.

2. Principle and Improvement of PGC Technique

2.1 Fundamental Principle of PGC Technique

Bragg period will change because of the variations of external strains or temperatures, as a result, FBG Laser frequency will also change accordingly. The unbalanced interferometer will convert the shift of the frequency or wavelength into the shift of phase[8].

$$\Delta \varphi = -\frac{2\pi n\Delta L}{\lambda^2} \Delta \lambda$$

(1)

where $\Delta \varphi$ is the shift of the phase, $\Delta \lambda$ is the shift of the wavelength, $n$ is the refractive index, and $\Delta L$ is the difference length of the interferometer.

PGC technique introduces a large amplitude phase shift at a frequency outside of the signal band so as to detect small phase shifts and eliminate fading caused by large environmental drifts. If a sinusoidal phase modulated signal with angular frequency $\omega_c$ and amplitude $C$ is imposed on one arm of fiber interferometer, then the light intensity detected at the output of the interferometer can be expressed as:
\[ I = A + B \cos \left( C \cos \omega t + \Delta \varphi(t) + \varphi_0 \right) \]  
(2)

where constant \( A \) and \( B \) are proportional to the input optical power, but \( B \) also depends on the mixing efficiency of the interferometer. \( \Delta \varphi(t) \) contains the signal of interest and \( \varphi_0 \) includes the initial phase difference of the two arms of the interferometer and the phase shift for environmental effects.

Mixing (2) with signal \( G \cos \omega t, \) and \( H \cos 2\omega t, \) respectively, then low pass filtering the high frequency items produces two channels of signals. With following operations including cross-multiplying, differential, integrating, and high pass filtering (see Fig. 1), the signal of interest \( B^2GHJ_1(C)J_2(C)\Delta \varphi(t) \) can be obtained where \( J_1(C) \) and \( J_2(C) \) are Bessel functions.

Thus the demodulated result can become \( GHJ_1(C)J_2(C)\Delta \varphi(t) \) from which it can be seen that the influence of optical power has been eliminated.

### 3. Realization PGC Technique on Compact RIO

#### 3.1 Structure of Compact RIO

Compact RIO can be viewed as a kind of embedded system. It is a product from national instruments (NI) and it belongs to programmable automatic controllers (PAC) which combine programmable logic controller (PLC) ruggedness with PC functionality under an open, flexible software architecture.

Compact RIO combines real-time and FPGA technologies to deliver high-performance in a small, rugged industrial control and acquisition platform. Compact RIO consists of three components, a reconfigurable I/O FPGA core, a real-time embedded processor, and industrial hot-swappable analog and digital I/O modules, as shown in Fig. 3.

1. The reconfigurable I/O FPGA core provides the reliability of dedicated hardware circuitry and the performance of true parallel execution in silicon;
2. The real-time embedded processor for stand-alone and distributed deterministic operation with a built-in web-based human-machine interface;
3. The industrial hot-swappable analog and digital I/O modules provide the direct connection to industrial sensors and actuators.

#### 3.2 Design of Program on FPGA Core

The FPGA core of compact RIO can be programmed by NI LabVIEW graphical development environment which can help to decrease the development time. In order to realize PGC technique on FPGA, there are several points to be emphasized:

1. The program should be developed as parallel execution to make sure PGC technique could be carried out simultaneously for different channels, thus compact RIO could demodulate signals from multiplexed FBG laser sensor system in real time.
2. Digital signal processing is done in a point-by-point procedure on FPGA which means the program will not allow the analog to digit converter to sample until the former point has been processed, therefore PGC technique should be separated into several parts (see Fig. 4) to perform so as to ensure a high sampling rate.
3. As resource of FPGA is limited, sometimes the parallel execution should be avoided in order to demodulate signals from more channels. We could desample the signals at the output of low-pass filter, thus the signals from different channels could be processed serially rather than parallelled. As a result, the resource of FPGA could be saved due to the multiplexed operations.
3.3 Design of Program on Real-Time Controller and Computer

The program on real-time controller is designed to control the sampling rate of analog to digit converter, the amount of data fetched from first in first out (FIFO) storage which stores the already processed data from FPGA, and the communication with computer.

Ethernet is used to connect with compact RIO and computer. The program on computer is also finished with LabVIEW. It is mainly designed to show the waveform of the demodulated results in time domain and also carries out fast Fourier transform (FFT) of the data to manifest the frequency domain of the demodulated results. The interface on the computer could be seen in Fig. 5.

4. Result of Experiment

A four-element FBG laser sensor system adopting WDM structure is completed with an unbalanced Michael interferometer (see Fig. 6). The system is tested in the pond with a loudspeaker in it. The sampling rate of analog to digit converter is 100 kHz and the frequency of the carrier is 10 kHz. The test tone is 600 Hz and the demodulated results in time domain and frequency domain could be seen in Fig. 7 and Fig. 8 respectively. Correlation coefficients between the test signal and the demodulated results can reach as high as 0.995 and the experiment shows that the dynamic range could be 120 dB@63 Hz.

5. Conclusions

This paper introduces peak-to-peak value detection method into PGC technique so as to avoid the influence on the demodulated results brought by the change of the light intensity. Besides, by taking advantage of the characteristics of compact RIO, PGC technique could be implemented in this embedded system to demodulate signals from multichannel simultaneously. The experiment was carried out by using compact RIO in the four-element FBG laser sensor system. The demodulated results show high coefficients with reference signal reaching 0.995. The final experimental results show the success of using compact RIO to perform PGC technique for FBG laser sensor system with several elements multiplexed.

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