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Self-calibration in a fiber optic sensing system using the walk-off compensation

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Abstract

We firstly present a concept of a self-calibration of the classical and quantum parameters' measurement using a fiber optic system. The measurement of the change in phase of the optimum entangled states' visibility is performed in terms of a walk-off length, i.e. birefringence. The applied physical parameters on the sensing fiber can be simultaneously measured and the self-calibration respecting the birefringence performed. The scheme of the entangled photons generation in fiber optic is reviewed and the walk-off on the polarization entangled states presented. The potential of self-calibration and simultaneous measurement using an interferometric sensing technique and fiber grating sensor are proposed and discussed. The walk-off on the entangled states in the thermal-controlled environment is presented and discussed.

Keywords: Self-calibration; Simultaneous measurement; Fiber optic sensor; Walk-off compensation

Recently, Yupapin and Suchat [1] and Suchat et al. [2] have demonstrated that the use of a fiber optic ring resonator could be used to generate a pair of entangled photons. The advantage of such a system is that there is no optical pumping part and component included in the system (i.e. an all-fiber optic scheme), which is a remarkably simple arrangement, and it is easy to implement in practical applications. However, the problem of the fiber optic property, known as a fiber birefringence, could affect the optimum entangled state visibility after traveling within a length of the fiber. Recently, Trojek et al. [3] have analyzed the timing-walk-off on the entangled photons in fiber optic, which could be compensated by using the phase retardation device (phase shifter). Such a device could be in the form of a bulky or fiber optic. To shift the polarization orientation angle, therefore, the use of the polarization controller (PC) device is recommended to adjust and preserve the entangled states along the fiber optic length. In this paper, we propose the concept of a fiber optic sensing measurement and self-calibration using two entangled photon states propagating within a fiber optic. The entangled states' walk-off due to the effects of the fiber optic properties, especially the polarization mode dispersion, i.e. fiber birefringence, and its related parameters that affect the timing-walk-off on the entangled photons are analyzed and discussed. The feasibility of using such a concept with the systems in applications is described in details.

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When the entangled photons generate and enter the fiber optic system, the amount of the walk-off on the entangled photons depends on the location where the photon pairs are within the fiber. This position is completely random due to the coherent nature of light in the fiber optic. To compensate the longitudinal timing-walk-off effect, a polarization controller is recommended to ensure that the polarization rotation is the same on both photons from the entangled pair. Additionally, the compensator fiber is used to change the relative phase ϕ of the states of the polarized light. Because of the change in birefringence, the tilting of the compensator allows one to apply a phase shift to the entangled states of the two photons, which are given by Eq. (1) [3]

$$|\psi\rangle_{12} = \frac{1}{\sqrt{2}}(|H\rangle_1 \otimes |V\rangle_2 + e^{i\phi}|V\rangle_1 \otimes |H\rangle_2) \quad (1)$$

In applications, the walk-off entangled state parameters involved in the measurement are related to the changes in the applied physical parameters such as force, stress, strain, heat, pressure, etc. However, the interested parameters in these proposed systems concern the fiber optic birefringence-related parameters, which is given by

$$\Delta\phi = \frac{2\pi(n_x - n_y)L_w}{\lambda} \quad (2)$$

where $\Delta n = (n_x – n_y)$ is the fiber optic birefringence, L_w is the entangled states walk-off length, and λ is the light source wavelength.

We begin with the first proposed system, which is as shown in Fig. 1. A pair of entangled photons is formed after light pulses circulating in a fiber ring resonator (EPR source), and the polarization controller applied. Such a system of an optical fiber interferometer incorporating the entangled states' generation setup is as shown schematically. The entangled photons are generated by the first part of the setup, which was well confirmed by Yupapin and Suchat [1]. This generates two pairs of entangled photons where one enters the sensing and the other enters the reference arm where both arms are coated to obtain the maximum reflected

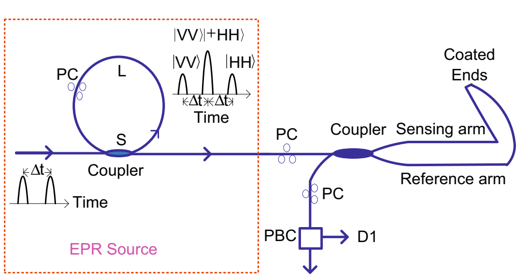


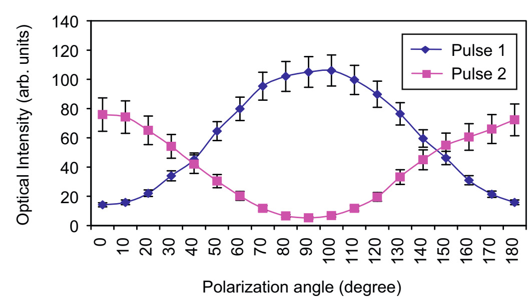
Fig. 1. Illustrates a schematic diagram of the quantum interferometric system. LD: laser Diode, PCs: polarization controllers, Ds: detectors, PBC: polarization beam combiner. S and L are stands for short and long fiber lengths.

powers. Only signal and idler photons entered a 2×2 coupler with a 50/50 coupling ratio and are detected by two detectors (D1 and D2). The difference between the round-trip times of the two arms is set at Δt. As a result, we can obtain the following polarization entangled state, which is given by [4]

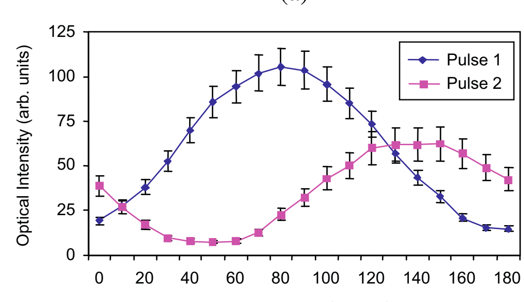
$$|\Phi\rangle = |2, H\rangle_s|2, H\rangle_i + \exp[i(\phi_s + \phi_i)]|2, V\rangle_s|2, V\rangle_i \quad (3)$$

The subscript (s, i) identifies whether the state is the signal (s) or the idler (i) state. The center wavelength of the signal is reflected and interfered being detected by detectors D1 and D2 and seen by using the interferometric technique. The entangled photons are interfered and recombined by a polarization combiner after being reflected back from the fiber ends of the same coupler. The applied physical parameter that performs on the sensing arm will change the fiber birefringence, which will be recovered by rotating the PC. The change in rotation angle then can be related to the change in fiber birefringence, i.e. physical parameter, which is given in Eq. (2).

For example, the entangled photons probability is as shown in terms of the optical output intensity, i.e. entangled photon visibility. It was generated by using the first part of the system, when the phase difference $\phi = 0°$ is as shown in Fig. 2(a) [1]. This is the optimum entangled photon visibility. Fig. 2(b) presents the optical intensity at the output of the polarization output, when the phase difference of the signal peak and the delay peak of the nonlinear fiber ring resonator is $\phi = 45°$.



(a)



(b)

Fig. 2. Graphs of the measured optical signals: (a) $\phi = 0°$ and (b) $\phi = 45°$ at room temperature, where pulse 1 and pulse 2 were detected by D1 and D2, respectively [1].