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Chapter

Introductory Chapter: An Overview the Methodologies and Applications of Fiber Optic Sensing

Shien-Kuei Liaw

1. Introduction

Fiber sensors have several advantages compared to some conventional sensors. They are lightweight and have a small size, high resolution, and good stability; fiber sensors not only are insensitive to electromagnetic interference but also can withstand high temperature and radiation. A variety of linear and nonlinear optical transduction mechanisms have been studied in the last 30–40 years, dealing with the conversion from all kinds of measurands to local measurable optical effects in the fiber. There are previous works, for instance, that designed temperature-compensated fiber Bragg grating (FBG) sensor for monitoring the stress [1], FBG-integrated spherical-shape structure for refractive index sensing [2], and D-shaped fiber combined with a FBG for refractive index and temperature sensing [3]. Fiber sensor can measure and/or monitor many parameters such as strain, weight, temperature, speed, pressure, and so on. Moreover, fiber sensor can also measure the variation of light intensity, wavelength, frequency, phase, and polarization by combining other detectors with optical fiber. Firstly, optical fiber sensors for temperature and pressure have been developed for measurement in oil wells. For example, a precise and real-time ammonia monitoring technique is important especially for gas sensing [3]. Once the gas leakage happens, an immediate alarm is helpful to prevent danger. Secondly, fiber sensing is also used to make a hydrogen sensor. Temperature can be measured by using a fiber that has evanescent loss with various temperature ranges or by analyzing the Brillouin scattering in the optical fiber. Thirdly, angle measurement sensors can be designed based on the Sagnac effect. In recent years, various sensing materials are available for biosensor fabrication, so various fiber-optic biosensors have been proposed and demonstrated. Finally, optical fiber sensors have been developed to simultaneous measurement of temperature and strain with very high accuracy by using fiber Bragg gratings.

2. Types of fiber-optic sensing

2.1 Intrinsic sensing and extrinsic sensing

According to the role optical fiber plays, fiber sensing can be divided into intrinsic sensing and extrinsic sensing. The intrinsic sensing is that the optical fiber itself plays as both the sensing element and the transmission media, as is shown in **Figure 1(a)**;

the extrinsic sensing is that the optical fiber just plays as the transmission media, as is shown in **Figure 1(b)**. Both of them are important and are frequently used in temperature sensing, strain sensing, or pressure sensing, depending on which parameters we want to measure. Specifically, intrinsic fiber-optic sensors provide distributed sensing over a long-distance zone [4], and extrinsic sensors can help us reach inaccessible places, for example, the measurement of temperature inside aircraft jet engines and the measurement of the high temperature inside the electrical transformer. Extrinsic fiber-optic sensors provide excellent protection of measurement signals against noise corruption, and they can be used to measure vibration, rotation, displacement, velocity, acceleration, torque, and temperature [5].

2.2 Types of fiber-optic sensing

Fiber-optic sensors can be split into two big categories: point-by-point sensors and distributed sensors. On the one hand, the point-to-point sensors are usually
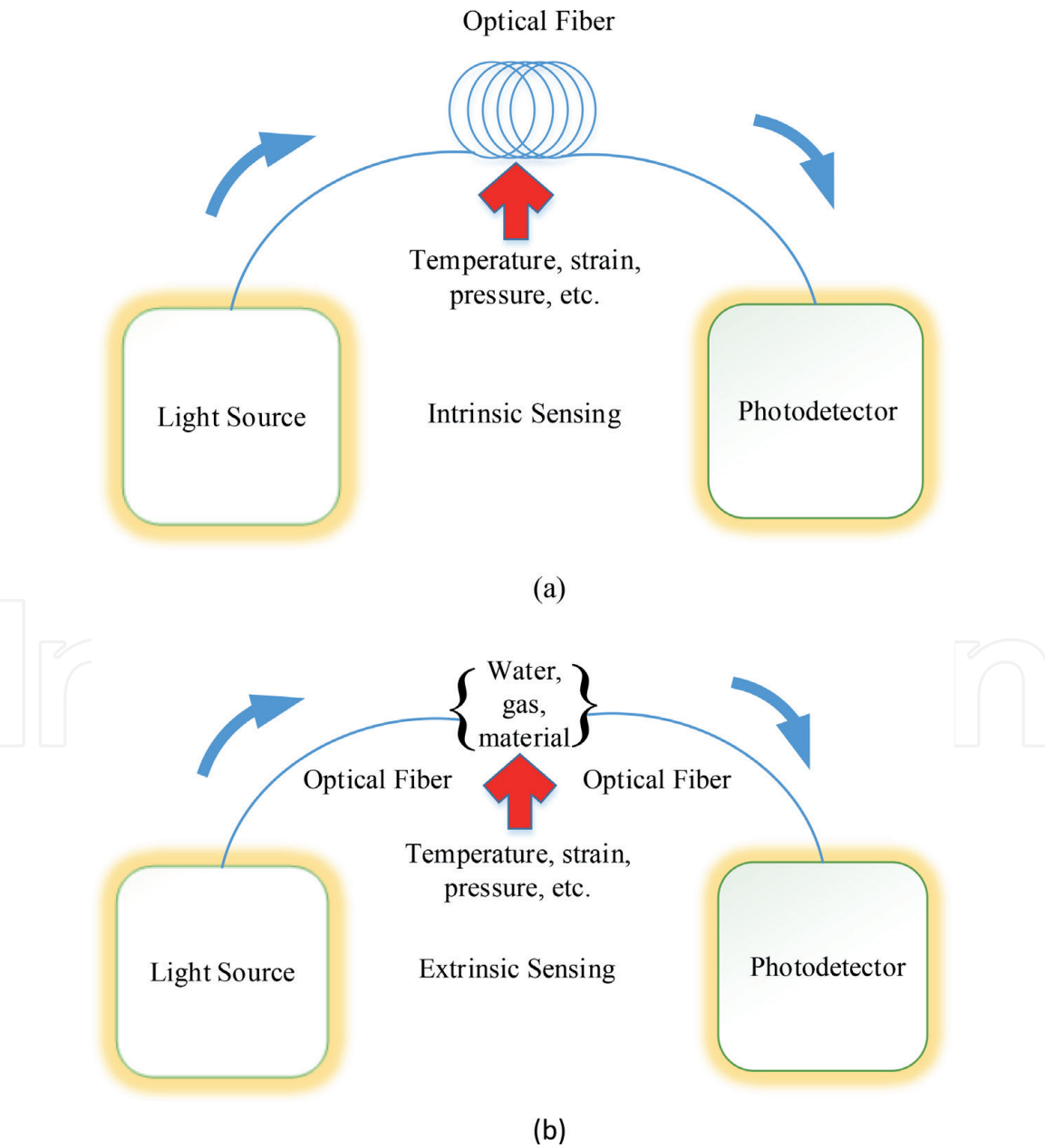

Figure 1.
(a) The intrinsic sensing, the optical fiber plays as both the sensing element and the transmission media; and (b) the extrinsic sensing, the optical fiber just plays as the transmission media.

based on FBG. They can measure parameters at a particular location where there is a FBG with high resolution and sensitivity. A standard FBG-based sensing system is shown in **Figure 2** with most required components. Using an optical switch (OSW), a broadband light source may transmit to bridge 1, bridge 2, or bridge 3, respectively, for strain, temperature, and/or stress sensing. Several FBGs are used to monitor multiple parameters/points at the same time. The optical switch is used to share the cost. FBG here is not only the sensing element but also the cavity end of fiber laser. The reflected signals are detected by an optical spectrum analyzer (OSA). Then the data may be in time analyzed by a data logger.

On the other hand, the detectable range of the distributed sensors is based on the Brillouin scattering effect with moderate resolution and limited distances. Nevertheless, a sensor head like a FBG is not required, so distributed sensors are more cost-effective than numerous FBG sensors in long-range sensing distance. A standard Brillouin optical time-domain analysis (BOTDA) sensing system is shown in **Figure 3** with most required components. Firstly, a highly coherent DFB laser source is split into pump source and probe source by using a 50/50 fiber coupler. An erbium-doped fiber amplifier (EDFA1) is used to boost the laser power. A pulse pattern generator is used to drive the electrooptic modulator (EOM1). Then a microwave sine wave around the optical fiber Brillouin frequency of ~11 GHz) is fed into the probe source. The signals are scrambled by polarization controllers before they arrive at the Mach-Zehnder modulators (EOMs). The pumped light at the left-hand side is further amplified by an EDFA2 and launched into the fiber under test (FUT) region. The reflected pumped light and probe light comes from other side travel through the optical circulator (OC) and then to EDFA3. A tunable filter or its equivalent is used to filter out pump backscattering and the upper sideband signal. Then the residual signal is monitored and analyzed by a real-time oscilloscope.

In general, point-by-point sensing is practical for short distance and remote monitoring up to 100 km. Distributed sensing based on the Brillouin scattering effect is used to detect strain and temperature for up to 10 km.

2.3 Fiber-optic sensing system

Figure 4 represents a standard fiber-optic sensing system [6]. There is a light source (laser or LED) launching into the optical fiber, and at the right-hand side is
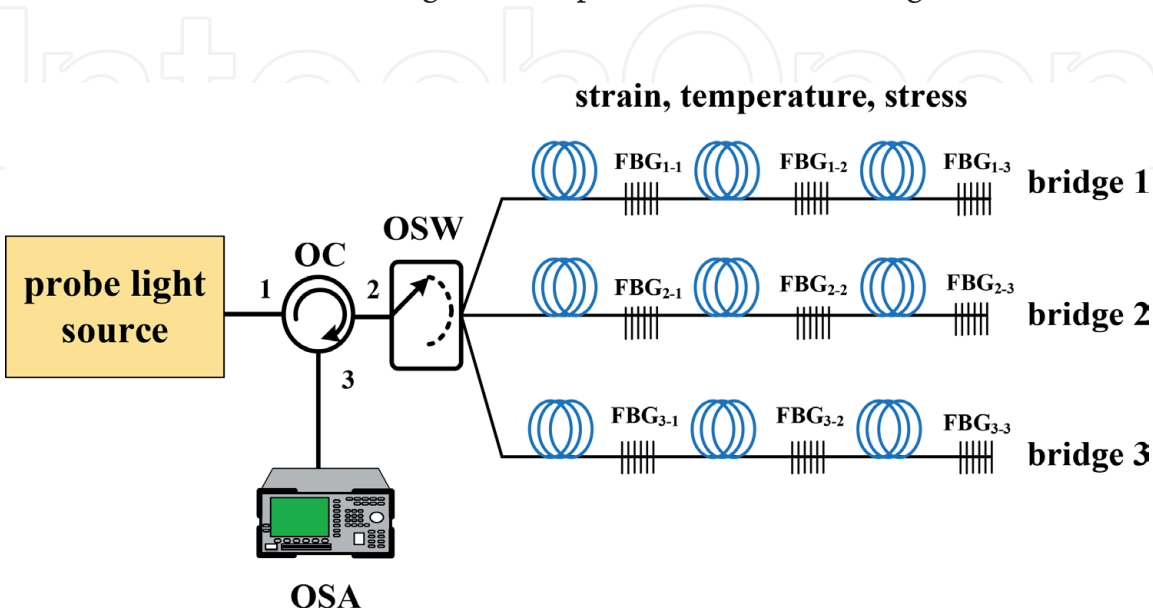

Figure 2.
An example of FBG-based sensing system: OC, optical circulator; OSW, optical switch; OSA, optical spectrum analyzer; FBG, fiber Bragg grating.
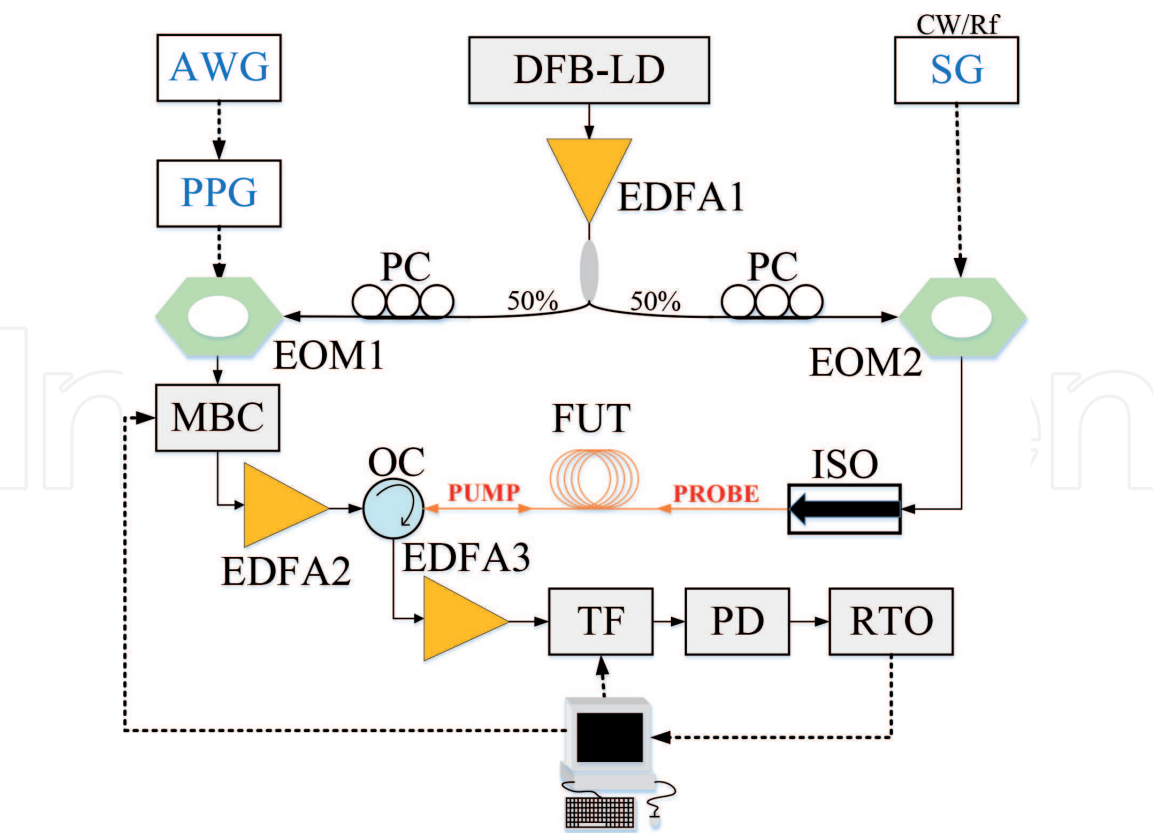
Figure 3.
An example of BOTDA setup: DFB-LD, distributed feedback laser diode; SG, signal generator; EDFA, erbium-doped fiber amplifier; PC, polarization controller; EOM, electrooptical modulator; ISO, optical isolator; AWG, arbitrary waveform generator; PPG, pulse pattern generator; MBC, modulator bias controller; MBC, modulator bias controller; PD, photodetector; RTO, real-time oscilloscopes; OC, optical circulator; FUT, fiber under test.
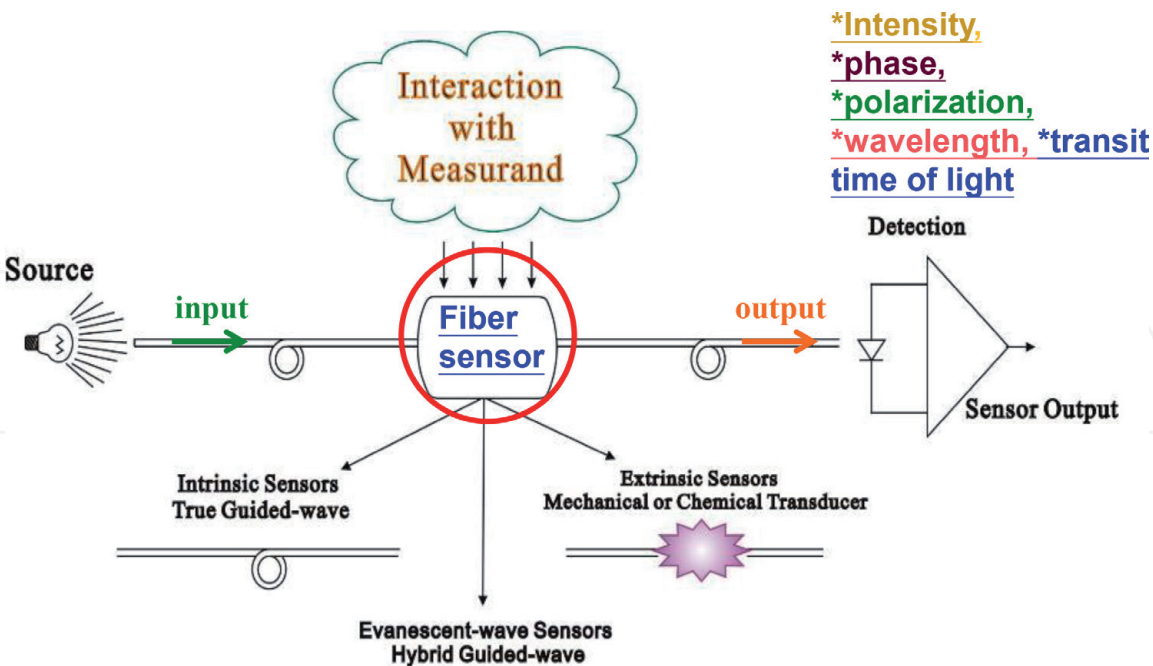

Figure 4.
A standard fiber-optic sensing system [6].

the detector sensing the signal output. The type of fiber sensing may be intrinsic sensing or extrinsic sensing. The parameters such as intensity, phase, polarization, wavelength, and other measurands can be detected and sensed when the light source passes through the monitoring zone where these parameters have direct or indirect effect on the propagating light source.

3. A brief review of previous works

In this section, some previous works of sensing are introduced and addressed. In [7], the authors proposed a FBG liquid level sensor based on the Archimedes' law of buoyancy [8]. They experimentally demonstrated the capability of the proposed device to perform the measurement of water level. It is quite simple to design the device for specific applications without changing the complex cantilever structure. In [9], a D-shaped fiber structure combined with a FBG for refractive index (RI) and temperature sensing is experimentally investigated. The possibility of simultaneous measurement of the RI and temperature relies on monitoring the resonance dip of the D-shaped fiber modal interferometer and the Bragg wavelength of the FBG. An online monitor of moisture concentration in transformer oil that permits the control of moisture buildup is proposed in [10]. The authors presented a methodology for measurement of moisture concentration in transformer oil using a poly(methyl methacrylate) (PMMA)-based optical FBG. In [11], the authors demonstrated a Brillouin optical correlation domain analysis (BOCDA) system with high-speed random access measurement and temporal gating scheme to extend the range of measurement. Dynamic strain applied at two points was selected arbitrarily along the fiber, and it was measured simultaneously [11]. Other Brillouin scattering effect based fiber sensing has also been addressed in [12]. In summary, fiber sensing is more and more important, and quite a few applications could be found in daily lives.

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References

[1] Ren F, Zhang W, Li Y, Lan Y, Xie Y, Dai W. The temperature compensation of FBG sensor for monitoring the stress on hole-edge. IEEE Photonics Journal. 2018;**10**(4). DOI: 10.1109/JPHOT.2018.2858847

[2] Gu M, Yuan S, Yuan Q, Tong Z. Temperature-independent refractive index sensor based on fiber Bragg grating and spherical-shape structure. Optics and Lasers in Engineering. 2019;**115**:86-89

[3] Jian S, Dong Y, Xiao H, Wu B, Xiao S. Refractive index and temperature sensor based on D-shaped Fiber combined with a Fiber Bragg grating. IEEE Sensors Journal. 2018:1-1

[4] Strong AP, Lees G, Hartog AH, Twohig R, Kader K, Hilton G. An integrated system for pipeline condition monitoring. In: International Petroleum Technology Conference; December 2009; Doha, Qatar

[5] Roland U, Renschen CP, Lippik D, Stallmach F. A new fiber optical thermometer and its application for process control in strong electric, magnetic, and electromagnetic fields. Sensor Letters. 2003;**1**(1):93-98

[6] Lee C-L. Optical fiber sensing lecture 2018. Taiwan: National United University

[7] Consales M, Principe S, Iele A, Leone M, Zaraket H, Jomaa I, et al. A fiber Bragg grating liquid level sensor based on the Archimedes' law of buoyancy. Journal of Lightwave Technology. 2018;**36**(20):4936-4941

[8] Keighley HJP. Archimedes' principle and flotation. In: Work Out Physics 'O' Level and GCSE (Macmillan Master Series). London, U.K.: Palgrave. p. 1986

[9] Dong Y, Xiao S, Wu B, Xiao H, Jian S. Refractive index and temperature sensor based on D-shaped Fiber combined with a Fiber Bragg grating. IEEE Sensors Journal. 2019;**19**(4):15

[10] Zhang W, Webb DJ. PMMA based optical fiber Bragg grating for measuring moisture in transformer oil. IEEE Photonics Technology Letters. 2016;**28**(21):2427-2430

[11] Zhang C, Kishi K, Hotate K. Enlargement of measurement range in Brillouin optical correlation domain analysis with high-speed random accessibility using temporal gating scheme for multiple-points dynamic strain measurement. In: Proc. SPIE 9634, 24th International Conference on Optical Fibre Sensors (OFS24); Curitiba, Brazil. 2015

[12] Motil A, Bergman A, Tur M. Invited, State of the art of Brillouin fiber-optic distributed sensing. Optics & Laser Technology. 2016;**78**:81-103