Chapter 1. Introduction

1.1 Background of the Proposed Research

The measurement of temperature has been playing a critical role in various technical areas from civilian to military applications. According to all recent major market surveys, sales of temperature sensors are far higher in numbers than those of other kinds. Due to the wide variety of applications and the wide range of temperatures to be measured and monitored, a multitude of varying physical principles is applied in temperature sensing.

The motivation of this research is to meet the recent increasing needs for optical fiber temperature sensors capable of operating accurately and reliably in harsh environments. Temperature is always one of the major indicators for the safety of the people's living and working environment. For instance, in our normal life fires following an earthquake usually cause heavy human casualties and property losses. Timely detection of temperature of environment will predict the occurrence of fires. In the oil industry, the safety of the oil field is a very important factor to insure the normal oil-recovering operation. Occurrence of explosions or fires in oil wells is susceptible to high temperature. In a nuclear power plant, temperature sensors are deployed in the reactor to control the nuclear reaction.

Harsh environments are often unavoidable in many engineering applications. These harsh environments may involve extreme physical conditions, such as high-temperature, high-pressure, corrosion, toxicity, strong electromagnetic interference, and high-energy radiation. Due to the severe environmental conditions, conventional temperature sensors are often difficult to apply. This situation has opened a new but challenging opportunity for the sensor society to provide robust, high-performance, and cost-effective temperature sensors capable of operating in those harsh environments.

Optical fiber-based sensors have many advantages over conventional electronic sensors for harsh environmental sensing applications. These include: small size, light weight, immunity to electromagnetic interference (EMI), resistance to chemical corrosion, avoidance of ground loops, high sensitivity, large bandwidth, capability of remote operation, and potential capability of operating at high temperatures [6]. These advantages have promoted a worldwide research activity in optical fiber harsh environmental sensing.

1.2 Temperature sensors

Generally speaking, temperature sensors are used for detecting the changes in temperature of the objects that people are interested in [1]. Most commonly they are called thermometers. Thermometers can be used for sensing not only the change of the thermal energy of the objects but also the change of the heat fluxes of the objects. In following sections, I will introduce some most commonly used temperature sensors in brief. Following that is our research focus — fiber optic sensor.

1.2.1 Thermocouple

Up to now thermocouples are the most commonly used temperature sensors due to its characteristic [2]. They work with the principle that when different metals are contacted with each other, there will be a voltage produced. The quantity of the voltage is associated with the difference of the temperature between the different metals. There are many different types of thermocouples such as type J, type K, type T and so on. Different types of thermocouples have different characteristic curve of the change of voltage with the change of the temperature, and different types of thermocouples are suitable for using in different temperature ranges.

1.2.2 Thermistors

Thermistors are based on the principle of when the temperature of the resistors changes, the electrical resistance of the resistors will change correspondingly. There are two kinds of thermistors. One is Negative Temperature Coefficient (NTC) thermistors that when the temperature of the resistors increases, the resistance of the resistors will be decreased. The other one is Positive Temperature Coefficient (PTC) thermistors that when the temperature of the resistors increases, the resistance of the resistors will be increased [3].

1.2.3 Liquid In Glass Thermometers

The principle of Liquid in glass thermometers are based on the temperature sensitive characteristic of the liquid such as mercury or alcohol. The liquid is sealed a glass tube. When the temperature changes, the liquid in the glass tube will expand or contract along the tube [1].

1.2.4 Resistance Temperature Detectors

Resistance temperature detectors (RTD) are based on a well-known principle that when their temperature is increased, resistivity of most metals will increase, and after cooling to the original temperature, resistivity of most metals will return to the original resistivity [4].

1.2.5 Radiation Thermometers

The principle of Radiation Thermometers (or Pyrometers) are that when the temperature of the object changes, the quantity of thermal electromagnetic radiation of the object will change correspondingly [5].

1.3 Fiber Optic Sensors

Fiber optic sensors can be used for the measurement of many physical or chemical properties [6]. The principle is based on that light in an optical fiber can be modified in response to an external physical, chemical, biological, biomedical or similar influence. Most properties can be detected with fiber optic sensors such as pressure, rotation, displacement (position), temperature, sound, strain, magnetic field, electric field, radiation, flow, liquid level, chemical analysis, vibration, etc.

1.3.1 Classification of Fiber Optic Sensors

Specifically, fiber optic sensors can be classified in terms of the type of perturbation or the principle of operation. Thus, they can be described by the chemical concentration, electrical field, strain, temperature, pressure, stress or the other physical measurand. The operating principles can be based on variations of intensity, phase, polarization, and wavelength.

More commonly, fiber optic sensors can be divided into two basic categories: intensity-based sensors and interferometric-based sensors. Generally intensity-based sensors are related to the displacement or some other physical perturbation that interacts with the fiber. The perturbation produces a change in received light intensity. Interferometric-based sensors commonly compare the phase of light in a sensing fiber to a reference fiber in an interferometer. The difference of the phase can be measured. Interferometric-based sensors are much more accurate than intensity-based sensors and can be used over a much larger dynamic range. However, they often require much more complex signal processing techniques. Thus often they are much more expensive.

1.3.2 Intensity-based Fiber Optic sensor

Intensity-based sensors measure the optical intensity that is a function of the perturbing environment, as shown in figure 1-1 [6]. The change of the optical intensity can be related to transmission, reflection, microbending, or other phenomena such as absorption, scattering, or fluorescence. Intensity-based fiber optic sensors can be divided into reflection sensors, transmission sensors, and microbending sensors.

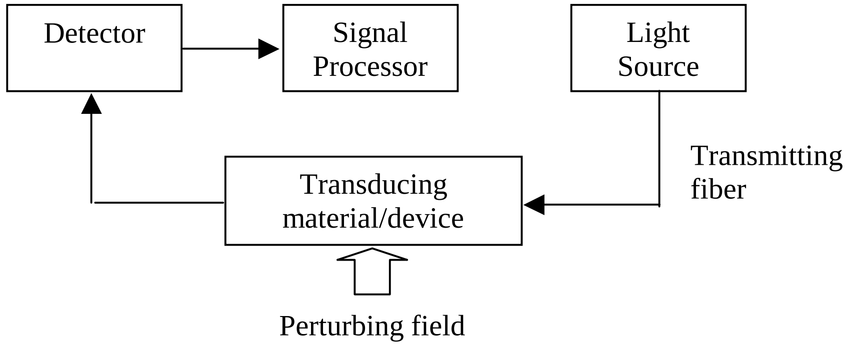

Figure 1-1. Intensity Sensor

1.3.3 Interferometric-based Fiber Optic sensor

Interferometric-based sensors take advantage of interferometric techniques to measure pressure, temperature, rotation, magnetic field, etc. Generally, the sensor uses a coherent laser light source and two single-mode fibers. The light is split and put into each fiber. If the environment perturbs one fiber relative to the other, a phase shift happens that can be detected precisely. The shift of the phase is detected by an interferometer. There are four interferometric configurations. They are the Mach-Zehnder, the Michelson, the Fabry-Perot, and the Sagnac [6].

Figure 1-2 shows the schematic of a Mach-Zehnder interferometer. The laser light source split its outgoing beam so that light travels in the reference single-mode fiber and the sensing fiber, which is exposed to the perturbing environment. If the light in the sensing fiber and the light in the reference fiber are exactly in phase after recombining, they constructively interfere. If they are out of phase, destructive interference happens and the received optical intensity is lower. Such devices have a phase shift if the sensing fiber has a length or refractive index change, or both.

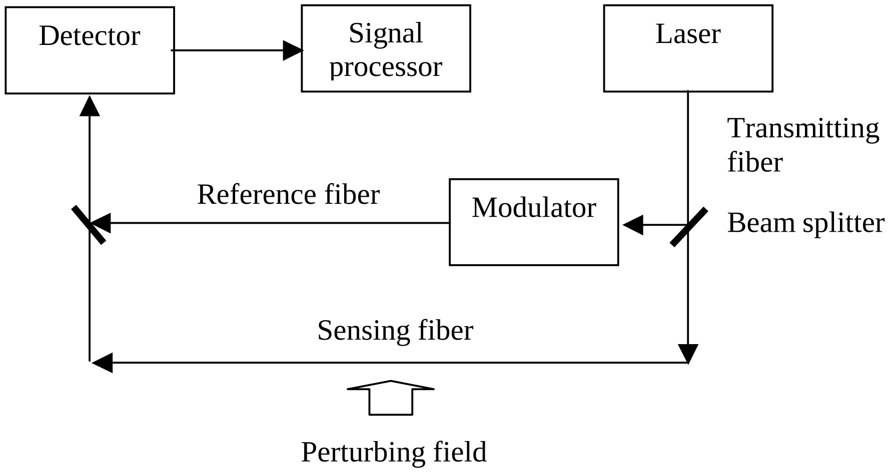

Figure 1-2. Interferometric Sensors (Mach-Zehnder interferometer)

In summary, fiber optic interferometric sensors usually have the advantages such as the design flexibility, the large dynamic range and high resolutions. However, because of the non-linear periodic characteristic of the interference signal, the accurate detection of the differential phase change of an interferometer turns to be a real challenge.

1.3.4 Advantage of Fiber Optic Sensors

Compared with other types of sensors, fiber optic sensors offer may benefits as following [7]:

1. Sensed signal is immune to electromagnetic interference (EMI) and radio frequency interference(RFI);
2. Intrinsically safe in explosive environments;
3. Highly reliable and secure with no risk of fire/sparks;
4. High voltage insulation and absence of ground loops and hence obviate any necessity of isolation devices like optocouplers;
5. Low volume and weight, e.g., one kilometer of 200um silica fiber weighs only 70 gm and occupies a volume of about 30 cm^3;
6. As a point sensor, they can be used to sense normally inaccessible regions without perturbation of the transmitted signals;

7. Potentially resistant to nuclear or ionizing radiation;
8. Can be easily interfaced with low-loss optical fiber telemetry and hence affords remote sensing by locating the control electronics for LEDs/lasers and detectors far away from the sensor head;
9. Large bandwidth and hence offers possibility of multiplexing a large number of individually addressed point sensors in a fiber network or distributed sensing i.e. continuous sensing along the fiber length;
10. Chemically inert and they can be readily employed in chemical, process and biomedical instrumentation due to their small size and mechanical flexibility;
11. High sensitivity, high accuracy and cost-effectiveness.

These advantages give us an opportunity to develop fiber optic sensors for accurate sensing and measurement of physical parameters and fields, e.g., pressure, temperature, liquid level, electric current, rotation, displacement, acceleration, acoustic, electric and magnetic fields and so on. These benefits have also promoted a worldwide research activity in optical fiber hash environmental sensing.

1.4 Scope of the Proposed Research

The major objective is to develop a robust fiber optic temperature sensor technology for harsh environmental sensing applications e.g. detection of fire occurrence. The research work proposed in this thesis, entitled "Self-Calibrated Intensity/Interferometric Based (SCIIB) Fiber Optic Temperature Sensor", is focused on three issues: 1) the improvement of the stability of fiber optic sensors by developing innovative techniques to provide fiber optic sensors with self-calibration capability so that the fluctuation of the source power and the change of the fiber loss can be fully compensated, 2) the optimal design and the development of the sensor probe fabrication techniques to maximize the working range of the fiber optic temperature sensors, and 3) design and development of a reliable fiber optic temperature sensor system for practical use.