Fiber-Optic Sensors and Their Practical Research in the Internet of Things

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Abstract: With the rapid development of the Internet of Things (IoT) technology, fiber-optic sensors, as a kind of high-precision and high-sensitivity measurement tool, are increasingly widely used in the field of IoT. This paper outlines the advantages of fiber-optic sensors over traditional sensors, such as high precision, strong resistance to electromagnetic interference, and long transmission distance. On this basis, the paper discusses the application scenarios of fiber-optic sensors in the Internet of Things, including environmental monitoring, intelligent industry, medical and health care, intelligent transportation, and other fields. It is hoped that this study can provide theoretical support and practical guidance for the further development of fiber-optic sensors in the field of the Internet of Things, as well as promote the innovation and application of IoT.

Keywords: Fiber-optic sensor; Internet of Things; Practical application

1. Introduction

Under the background of rapid development of science and technology, the Internet of Things (IoT), as a bridge connecting the physical world and the digital world, is changing people's way of life and way of work. IoT uses a variety of sensor devices to collect, transmit, and process information and support intelligent decision-making. Among many sensor technologies, optical fiber sensors are gradually becoming a research hotspot in the field of IoT due to their unique advantages, such as strong anti-interference ability, long transmission distance, high measurement accuracy, etc. Fiber-optic sensors use the transmission characteristics of light to sense and measure physical quantities in the environment, such as temperature, pressure, strain, etc. Fiber-optic sensors have higher sensitivity and stability compared to traditional electrical sensors and perform well in harsh electromagnetic environments. This makes fiber-optic sensors have a wide range of applications in IoT, such as smart grid, intelligent transportation, environmental monitoring, medical diagnosis, and so on. Therefore, an in-depth study of the practical applications of fiber-optic sensors in the Internet of Things is of great academic value.

2. The concept of fiber-optic sensor

A fiber-optic sensor is a high-precision sensing device based on fiber-optic technology. Its basic working principle is mainly based on changes in the electro-optical properties of light. It mainly involves the transmission, modulation, and demodulation process of light. When light from a light source enters a modulator through a fiber-optic line, this light interacts with external parameters to be measured, resulting in significant changes in certain electro-optical properties of light, such as its compressive strength, optical wavelength, frequency, position, or polarization state. The optical signals are subsequently fed again through the fiber-optic line to the demodulator, which further processes these optical signals to obtain specific values of the measured parameters [1]. Fiber-optic sensors consist of a light source, an incoming fiber, an outgoing fiber, a light modulator, a light detector, and a demodulator, where the fiber-optic is not only used as a light-conducting medium but also often as a sensitive element.

Fiber-optic sensors offer many significant advantages over conventional sensors. Its high sensitivity and high resolution ensure the accuracy of the measurement results. The characteristics of fiber-optic sensors facilitate easy networking, allowing the construction of large-scale sensing networks. This enables rapid transmission and processing of information. Fiber-optic sensors also provide continuous distributed detection and long-distance detection capabilities, allowing for uninterrupted monitoring across a wide spatial range. Additionally, the low energy loss and anti-electromagnetic interference properties ensure stability and reliability in complex environments. Furthermore, the detection range is not only dependent on the light-conducting medium but also on the sensitive element itself. The adjustability of the detection range enhances the versatility of fiber-optic sensors. The convenience of engineering construction simplifies their implementation. Strong environmental tolerance and excellent anti-interference capabilities further broaden the application of fiber-optic sensors. These features make fiber-optic sensors particularly suitable for small spaces, humid environments, and other special scenarios with strong corrosive conditions [2].

3. Practical applications of fiber-optic sensors in the Internet of Things

3.1. Environmental monitoring field

Fiber-optic sensors are widely used in the field of environmental monitoring because they have many unique advantages, such as high sensitivity, resistance to electromagnetic interference, high temperature resistance, corrosion resistance, etc., which makes them particularly suitable for accurate measurement in complex and changing environments [3].

Fiber-optic sensors are useful for air quality monitoring to monitor the concentration of pollutants in the atmosphere, such as sulfur dioxide and nitrogen dioxide in real time. These sensors can quickly respond to environmental changes and provide continuous monitoring data to help the environmental protection department understand the air quality situation promptly and provide a scientific basis for pollution control and environmental governance.

Fiber-optic sensors can be used in water quality monitoring to monitor parameters such as temperature, pH, dissolved oxygen, turbidity, etc. in water [4]. Deploying fiber-optic sensor networks in water bodies can achieve real-time monitoring and early warning of water quality, help the monitoring department detect and deal with water pollution problems on time, and protect the safety and sustainable use of water resources.

Additionally, fiber-optic sensors can be used for soil monitoring. Monitoring the temperature, humidity, pH, salinity, and other parameters in the soil provides insights into the quality and health of the soil, providing scientific guidance for agricultural production and land management.

In the field of environmental monitoring, fiber-optic sensors can also be combined with other IoT devices to build a complete monitoring system. For example, combining fiber-optic sensors with wireless transmission technology can achieve remote real-time monitoring and data transmission. Combined with a data analysis platform, the monitoring data can be processed and analyzed to extract valuable information and provide powerful support for environmental management and decision-making.

3.2. Intelligent industrial field

With the rapid development of Industry 4.0 and intelligent manufacturing, the application of optical fiber sensors in the field of intelligent industry gradually highlights its importance and advantages. Fiber-optic sensors not only have the characteristics of high precision, high reliability, and high stability but also can operate stably for a long time in harsh industrial environments and provide accurate data support for industrial production [5].

Fiber-optic sensors can monitor the operating status of industrial equipment in real-time, such as temperature, pressure, vibration, and other parameters. The real-time monitoring of the state of the equipment can detect abnormalities in the equipment in time, carry out preventive maintenance, and avoid production interruptions caused by equipment failure. Simultaneously, combined with data analysis and processing technology, fiber-optic sensors can also optimize the production process, and improve product quality and production efficiency.

Fiber-optic sensors can accurately measure a variety of parameters in the production process, such as temperature, flow rate, liquid level, and so on. By integrating with other IoT devices and systems, fiber-optic sensors can automate the control and optimization of production lines [6]. For example, in material transfer and sorting systems, fiber-optic sensors can monitor the location and status of materials in real-time to ensure that materials can be transferred to the designated location accurately and efficiently. Real-time monitoring and adjustment of the production process can ensure the stability and consistency of product quality.

Fiber-optic sensors can be used for industrial safety monitoring, such as fire warning, and gas leakage detection. Real-time monitoring of gas concentration, temperature, and other parameters in the environment, once abnormalities are detected, you can issue a prompt alarm to ensure the safety of industrial production.

Fiber-optic sensors also exhibit excellent corrosion resistance and high temperature tolerance, enabling stable performance in some harsh industrial environments. For example, in industries such as steel and chemicals, where conditions involve high temperatures, high humidity, and severe corrosion, fiber-optic sensors can operate reliably over long periods. This stability ensures smooth industrial production and provides a strong guarantee for operational efficiency.

3.3. Medical and health field

Fiber-optic sensors are not electrically charged and exhibit excellent anti-electromagnetic interference, lightweight and bendable properties, as well as superior radiation and corrosion resistance. These qualities present broad application prospects in the field of medical and health care. Especially in special occasions where space is limited, electromagnetic interference is strong, and the environment is prone to corrosion, fiber-optic sensing technology has become an ideal choice for solving the data acquisition, transmission, and detection problems of IoT sensing systems [7]. Furthermore, its strong multiplexing capability enables the integration of multiple sensors on a single optical fiber and the construction of an efficient optical fiber sensing network, thus greatly enhancing the speed and efficiency of IoT information extraction.

In medical and health applications, fiber-optic sensors are cleverly implanted into everyday items such as wristwatches and belts for real-time monitoring of the body's physiological parameters like blood pressure,

heart rate, pulse, oxygen saturation, and so on. This continuous, non-invasive monitoring provides doctors with an accurate and reliable basis for diagnosis, helping to achieve individualized and precise medical services. Meanwhile, fiber-optic sensors can also be applied to assistive devices such as wheelchairs, helping to collect data on the lives of the disabled and deal with potentially dangerous situations in real-time.

Fiber-optic sensors also play an important role in the early diagnosis of a disease. Optical detection of diseased tissues by fiber-optic sensors can monitor changes in the optical properties of tissues in real-time, thus achieving early detection and precise positioning of diseases. This improves the accuracy and precision of disease diagnosis and provides strong support for early treatment of diseases.

During inhaled hydrogen medical therapy, the narrow space of the medical mask and nasal catheter is extremely demanding on the sensors. Fiber-optic sensors, with their small size, lightweight, bendability, intrinsic safety, and explosion-proof features, can achieve real-time monitoring and control of multiple parameters such as hydrogen concentration, uniformity, temperature, and humidity in a small space. Moreover, by multiplexing multiple sensors with a single optical fiber, an efficient sensing network can be constructed to achieve real-time online monitoring and precise treatment [8].

3.4. Intelligent transport field

The intelligent transportation field is one of the important fields where IoT technology can be widely applied and fiber-optic sensors provide strong support for the construction and development of intelligent transportation systems with their characteristics of high precision, high reliability, and strong anti-interference [9]. Traffic management departments install fiber-optic sensors at key locations such as roads and bridges, and the data collected consisting of real-time monitoring of traffic flow, speed, and other traffic parameters, provide an important reference for traffic scheduling and route planning.

Fiber-optic sensors can be combined with high-definition cameras to achieve real-time monitoring and identification of vehicles. Using image processing technology, it can identify the vehicle type, license plate number, and other information, which is convenient for the investigation and handling of traffic violations and vehicle tracking.

Fiber-optic sensors can monitor real-time road conditions, such as road humidity, temperature, cracks, and so on. These data can help the traffic management department detect road problems in time and take corresponding measures to ensure road safety and smoothness.

Moreover, fiber-optic sensors can be combined with traffic signal light systems to achieve intelligent signal light control. This can be done through real-time monitoring of traffic flow and road conditions, adjusting the signal timing, and improving road traffic efficiency and safety.

Fiber-optic sensors can also be integrated with Global Positioning System (GPS), wireless communications, and other technologies to provide real-time accurate data support for intelligent traffic management systems. This helps to achieve interconnection between vehicles and traffic infrastructure, traffic management systems, real-time sharing of traffic information, and collaborative processing to promote the smooth management of intelligent traffic [10].

4. Conclusion

With the rapid development of the Internet of Things (IoT) technology, fiber-optic sensors, as a key component of it, are becoming increasingly important. This paper systematically analyses and discusses the optical fiber sensor and its application practice in the Internet of Things, and summarizes the basic principles, characteristics, and multiple application areas of optical fiber sensors. It provides an in-depth understanding of the performance

and effect of fiber-optic sensors in practical applications and also recognizes the extensive prospects of fiber-optic sensors in IoT applications. Fiber-optic sensors, with their advantages of high precision, strong anti-interference ability, and long-distance transmission, provide a powerful sensing capability for IoT, which can more accurately obtain environmental information for smarter decision-making. Looking to the future, with the continuous progress of technology and cost reduction, fiber-optic sensors will become more popular and their application scenarios will be more extensive. Simultaneously, with the in-depth development of IoT technology, the integration of fiber-optic sensors with other sensors and technologies will also become a hotspot for research, providing strong support for the intelligence and efficiency of IoT.

In conclusion, the application of fiber-optic sensors in the Internet of Things is promising but still requires continuous research and innovation. It is expected that more researchers and practitioners will join this field in the future to jointly promote the development and application of fiber-optic sensors in IoT.

Disclosure statement

The author declares no conflict of interest.

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