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A STUDY ON UTILIZATION AND ADVANCEMENT OF FIBER OPTIC SENSORS

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Abstract

Sensors based on fiber optics have seen widespread use in structural monitoring in recent years. Because of their modest size, they may be extensively employed in structural parts of many kinds. New sensing technologies for civil constructions' health have been developed in recent years thanks to developments in optical fiber fabrication. An outline of our study into the creation of structural fiber optic sensors is given here. Fiber optic sensors can accurately monitor strain, stress, and temperature in a variety of constructions, as shown by this study. Several instances of structural components' strain, stress, and temperature have been shown in this study. Civil engineers now have a good option for monitoring civil infrastructure performance because to recent advancements in fiber optic sensor technology. Due to their compact size, high resolution, and long-distance signal transmission capabilities, fiber optic sensors are a suitable choice for a variety of applications. As an added benefit, they're impervious to electromagnetic and radio frequency interference, and they can accommodate numerous probed sensors concatenated onto a single fiber. Fiber optic sensors provide a number of benefits over conventional damage detecting techniques and equipment, at least in certain instances.

Keywords composite sensors, strains, crack detection, distributed measurements

Introduction

In the 1960s, the discovery of the laser sparked a renewed interest in optical devices for data transmission. Researchers were interested in fiber optics because of the laser's potential for data transmission, sensing, and other uses. Microwave and other electrical devices cannot transmit the quantity of data that laser systems can. The unhindered propagation of the laser beam through the air was the first experiment with the laser. Researchers have also used a variety of waveguides to transmit laser beams in their research. When it came to transmitting light, glass fibers quickly became the most popular choice. Optical fibers were first unable to replace coaxial cables due to their high loss levels. Fiber optic technology has revolutionized the telecommunications business in recent years. When light travels via an optical fiber, a FOS monitors a physical quantity by modulating its intensity, frequency spectrum, phase, or polarization in accordance with that light. With the help of this gadget, light beams may be transformed into electrical signals. Optical sensors may be found in a variety of devices, from computers to motion sensors, since they have so many uses. For example, when the door to a dark compartment within a photocopier is opened, light controls the sensor by growing in electrical productivity and activating the electric reaction and halting the photocopier machine for safety. An important distinction is often drawn between exterior and internal effects of fiber optic sensors (FOSs). Extrinsic sensors are those in which the transducers are external and the optical fiber only records and sends the sensed data of the measurand amount. In cases when the FOSs are a component of the optical fiber rather than separate from it, these FOSs are referred to as "intrinsic sensors".

Literature review

Jian Li et.al (2022) It has been proved that Raman distributed optical fiber sensing is a mature and adaptable approach that provides tremendous flexibility and effectiveness for the distributed temperature monitoring of a broad variety of engineering applications. Fast growth and wide range of applications have made it an essential tool for scientists and manufacturers alike. While classical Raman distributed optical fiber sensing has four theoretical or technological bottlenecks: Differences in optical attenuation, a poor signal-to-noise ratio (SNR) of a system, and a fixed error in a Raman demodulation equation limit the system's ability to accurately monitor temperatures. In a nutshell, ii) the sensing range and spatial resolution are incompatible. Third, the SNR and measurement time are at odds with each other. Dual-parameter detection is not possible with Raman distributed optical fiber sensing (iv). In light of the aforementioned theoretical and technological snags, this research examines advancements in performance upgrades and typical Raman distributed optical fiber sensing applications. It is possible to improve the performance and accuracy of these systems by integrating this optical system technology with knowledge-based technology, such as demodulation.

Lokendra Singh et.al; (2021) Small size and resilience to electromagnetic radiation are just a few of the unique qualities of optical fibers that have found applications in everything from structural monitoring to biological sensing. Optical fibers have found usage in industrial processes, environmental monitoring, food processing, and therapeutic applications thanks to optical transducers, integrated electronics, and innovative immobilization technologies. Microorganisms including bacteria, viruses, fungus, and protozoa may also be detected via optical fiber sensing studies. The increasing number of articles demonstrates optical fibers' acceptance in biosensing applications. In this chapter, optical fiber biosensors, their geometries, and the steps required to create them are described in detail. This section might represent a turning point in the careers of the new lab's founders.

Ramji Tangudu et.al (2021) For monitoring the temperature of the surrounding environment, the distributed temperature sensing (DTS) system is a valuable tool. For example, the fiber optic DTS system may be used to monitor oil and gas pipelines, power cables, transformers, fire detection, nuclear facility monitoring, and other possible uses. Fiber-optic DTS systems have been discussed in this study, along with its operational principles, problems, and possible applications. In addition to the assessment of fiber optic DTS system development and research, we have also examined a variety of commercially existing DTS systems and their prospective uses.

JingwenLi (2020) There has been an increase in research and development activities in refractive index measurement as it has been more widely used in a variety of sectors including chemistry, biology and medicine, the food industry, process control and environmental monitoring. High sensitivity, tiny fingerprints, high levels of integration, compatibility with hostile environments, and the possibility to enable real-time and remote analysis make optical fibers a particularly attractive platform for refractive index sensing. Fiber-optic refractive index sensors have been suggested and developed in a variety of designs and techniques up to this point. In this work, we will discuss the most widely used fiber-based refractive index sensors in the visible and infrared ranges, and quickly outline their benefits and disadvantages. For refractive index sensing applications, the recent development of several categories of THz waveguide platforms has been reviewed in light of the significant advantages of THz waves such as extended probing length, non-damage to biological samples, unique fingerprints of biological samples, and non-ionizing feature It's time to wrap things off with a look towards the future of this subject.

R Correia et.al (2018) Small size, no electromagnetic interference, high sensitivity, and the ability to design multiplexed or distributed sensing systems are just a few of the unique properties of optical fiber sensors (OFS), which have made them a popular choice for everything from structural health monitoring to biomedical and point-of-care instrumentation. However, there is a large amount of research on the use of OFS in healthcare, despite the fact that this is its primary commercial use. This study examines the many kinds of OFS and their most current healthcare uses. Clinicians will be able to learn more about OFS technology, as well as how it might be used in healthcare, through this guide. An focus on current (2015–2017) studies is placed on the use of OFS in healthcare to avoid duplicating recent review publications. With rare exceptions, the bulk of research into the creation of biological OFS takes place in the laboratory. Medical gadgets based on optical fibers have yet to realize their full potential in healthcare, and ways for promoting their use are considered. Considering these aspects early on in the device development process is critical to a successful transfer of sensor technology into clinical practice.

OPTICAL FIBERS

For the transmission of light, optical fibers (also known as optical fibers) are transparent fibers, most often constructed of glass or plastic. The strands are about the diameter of a human hair and are very flexible. Data may be transported across vast distances using the most recent technology available. Massive volumes of data. Optical fibers have been utilized to transmit light and audio information for many years, resulting in distortion-free music. In addition, fiber optics may be used in medical procedures, autos, and planes for interior inspections.

Despite the fact that fiber optics was initially developed in the 1930s, it was only in the late 1960s that this technology began to see widespread use. When phone companies began switching to fiber cable for long-distance connections in the 1980s, a significant uptick occurred. As time went on, all transmission systems and networks began to use fiber-optic connections.

Glass fibers are usually utilized in long-distance telecommunications because they have a lower optical attenuation than clear plastic fibers. In the communications industry, both multi-mode and single-mode fibers are employed, with multi-mode fiber used for short lengths (up to 500 m) and single-mode fiber used for long distance lines. As a result of the higher cost of single-mode components compared to multi-mode ones, these devices are more difficult to produce and need more precise tolerances to couple light into and between single-mode fibers. An optical fiber relay system includes a transmitter for creating and encoding signals, an optical fiber for transmitting those signals over long distances, an optical regenerator for boosting the signal across long distances, and an optical receiver for receiving and decoding those signals. Bundles of optical fibers are referred to as optical cables. The outer layer of each bundle is a jacket. The core, cladding, and buffer coating are all components of an optical fiber. The core is where light flows through the fiber (plastic coating that guards the fiber from break and moisture). When light hits the reflective surface of the cladding, it is internally refracted, zigzagging through the fiber rather than escaping.

Single-mode and multi-mode optical fibers are the two main varieties. Light from 1,300nm to 1,550nm may be transmitted over a single-mode fiber, which has a diameter of roughly 3.5 x 10-4 inches or 9 microns. LEDs may transmit infrared light (with a wavelength ranging from 850 to 1,300nm) using multi-mode fibers, which have bigger cores (2.5 x 10-3 inches or 62.5 microns in diameter). Fibers composed of plastic with a big core (0.04 inches or 1 mm diameter) and emitting visible red light of wavelength 650 nm from LEDs are available for use in this application.

Optical fibers provide several advantages over copper lines, including lower cost, thinner construction, more capacity, reduced signal degradation, digital signal transmission, nonflammability, light weight, and flexibility. Low-power transmitters are used instead of high-voltage electrical transmitters for copper lines because signals deteriorate less slowly. The signal that emerges from a fiber cable is identical to the signal that went into the cable in the first place. The electromagnetic interference and crosstalk from adjacent cables are not a problem for an optical cable's signal transmission because of its construction. Information about Fiber Optics, Fiber Optic Transmitters, and Fiber Optic Receivers may be found on this website, as well as other related topics. CCNA Exams and Fiber Optics are partners.

FIBER OPTIC SENSORS

Fiber optic sensors may be used to monitor strain, temperature and pressure. Fiber optic sensors provide benefits over traditional electrical sensors in certain applications because of their compact size and the fact that no electrical power is required at the distant site. Sensors for measuring temperature and pressure in oil wells have been created using optical fibers. In this case, the fiber optic sensor is the best choice since it can operate at temperatures that are too high for semiconductor sensors (Distributed Temperature Sensing). Optical gyroscopes, like those used in the Boeing 767 and certain automobile models (for navigation), and hydrogen microsensors are alternative applications using optical fiber as a sensor.

In the field of lighting, fibers are a common material of choice. They serve as light guides in a variety of fields, including medicine and other fields where direct line-of-sight to the objective is not possible. Sunlight from the roof is sent throughout the building using optical fibers in certain structures (see non-imaging optics). Signs, artwork, and fake Christmas trees all make use of optical fiber lighting. One light source is all that is needed at Swarovski stores to illuminate their crystal displays from many perspectives. LiTraCon, a light-transmitting concrete construction material, contains optical fiber as an essential component. Images may be captured using a variety of optical fiber-based techniques. When using an endoscope, which is a long and narrow imaging equipment that is used to see through a tiny hole, a coherent bundle of fibers is employed together with lenses. To perform minimally invasive exploratory or surgical operations, endoscopes are employed (endoscopy). An industrial endoscope may be used to investigate hard-to-reach areas, such as the guts of a jet engine. An erbium-doped optical fiber may be utilized as the gain medium for a laser or optical amplifier. By splicing a small segment of doped optical fiber into a standard optical fiber line, rare-earth doped optical fibers may enable signal amplification. In addition to the signal wave, a second laser wavelength is connected into the line and optically pumped into the doped fiber. The doped fiber carries both wavelengths of light, allowing the second pump wavelength to transfer energy to the signal wave. It is the stimulated emission that results in the amplification. Physicists employ optical fibers with a wavelength changer to gather scintillation light. Low-power electronics in challenging electrical environments may benefit from optical fiber supply (about one watt). Electronics in high-power antenna components and measuring devices used in high voltage transmission equipment are examples of this kind of technology.

TYPES OF FIBER OPTIC SENSORS

Intension-metric and interfero-metric fiber optic stress sensors are two of the most common types. While an interferometry sensor uses the detected induced phase shift in light passing via the optical fiber as its basis, an intension-metric sensor uses fluctuations of the radiant power delivered. Small bends in an optical fiber may be introduced by external pressures (such as compressive stress), which couples light out of the cable and so changes the intensity of light transmitted through the fiber. It is

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customary to use a micro-bend sensor to measure intension. Sensors of the Fabry-Perot and Bragg grating types are interferometric sensors. There are two mirrors arranged in line with the optical fiber in Fabry-Perot sensor. Strain induces a noticeable phase shift in the light frequency as a result of variations in the longitudinal mirror spacing. Figure 1 depicts two examples of these sensors.

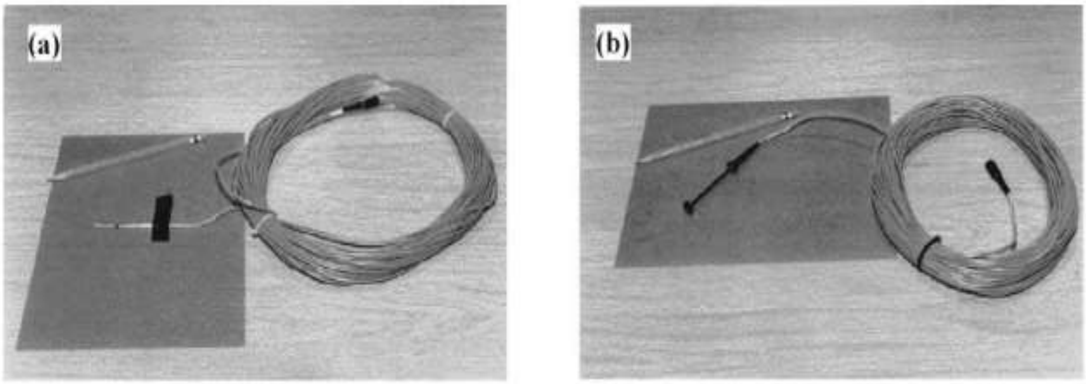

Figure 1. Two Types of Fabry-Perot Fiber Optic Sensors

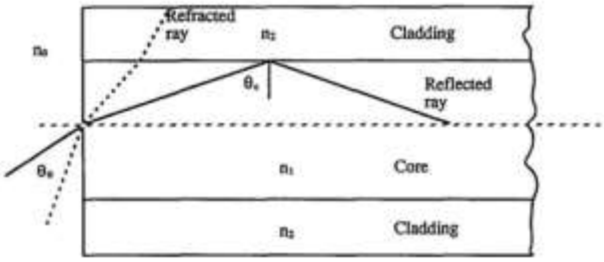

Figure 2. Basic Geometry of Optical Fiber Sensor

In order for the Bragg grating sensor to work, the optic fiber core must have a certain index of refraction. The wavelength of reflected light is affected by the spacing of these periodic fluctuations, which is affected by the longitudinal strain in the fiber. The second example is shown in Figure 2.

TYPICAL FOSS

Crack sensors

Most concrete constructions collapse because of fissures in the material. It is possible to determine the extent of a concrete structure's deterioration by keeping an eye out for cracks. Although several non-destructive evaluation methods have been developed for the identification of damage, all of them have the same constraint that continuous assessment of fractures cannot be conducted in situ over the service life of buildings, which is a major drawback. Newly designed fiber optic crack sensors have given an excellent answer to this issue. Fiber optic fracture sensors

For fracture detection, some researchers have employed FOSs. Measurements of fracture development and crack displacement, such as longitudinal crack separation and transverse shear crack displacement, were carried out by Wanser and Voss (1994) using multimode OTDR. The attenuation of light transmitted in the fiber optic crack sensors as a result of surface crack formation was measured by Habel (1995) for real-time fracture detection and crack growth rate. The FOSs were employed by Liu and Yang (1998) in order to monitor concrete cracks based on the microbending of an optical fiber spanning fractures using OTDR. Engineers Lee et al. (2000) showed the use of IOFS to track fatigue fracture propagation in steel structures by detecting changes in stiffness at or around the crack location.

For all its effectiveness in the field, fiber optic crack sensors still come with a number of drawbacks. If a break develops in a tiny location that isn't well-known a priori, traditional "point" sensors — which measure strain at a single local place — won't be able to detect it (Ansari and Navalukar 1993). Many tiny cracks can't be distinguished from a single broad open fracture by integrated sensors, which detect displacement between two spots separated by a significant distance (Wolff and Miesseler 1992).

As a solution to overcome these issues, Leung and colleagues (2000) developed the fiber optic "distributed" sensor that can detect the formation of cracks without requiring a priori knowledge of the exact crack locations, perform continuous monitoring once the crack is formed, and detect and monitor a large number of cracks with only a small number of fibers.

An example of how it works may be seen in Figure 3, which depicts a "zigzag" sensor embedded in a bridge deck at its base. The backscattered signal vs. time follows a rather consistent pattern prior to the creation of fractures.

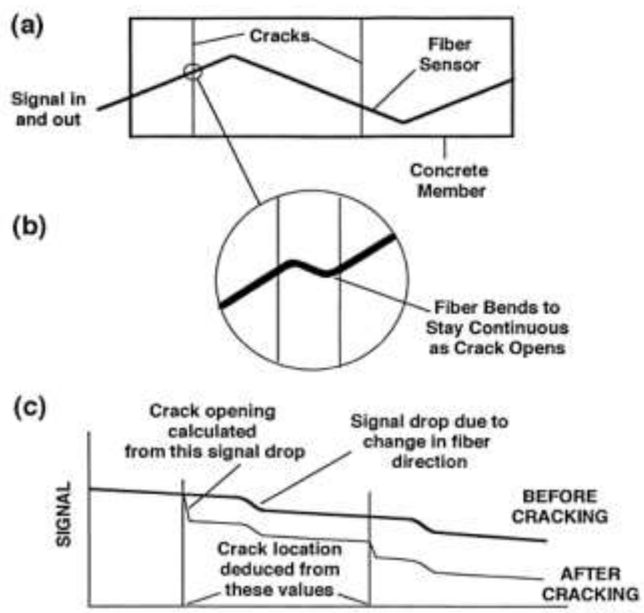

Fig. 3 The novel crack sensing concept (Leung et al. 2000)

curvature that is easy on the eyes (the upper line in Fig. 3c). The loss of signal in the fiber's straight sections is most likely owing to the cladding's absorption of light. Bending loss is caused by dissipating light energy in the cladding, which may vary depending on the radius of the curvature of the fibers. In order to remain continuous, a fiber crossing the fracture at an angle different than 90 degrees must be bent when a crack occurs in the construction (Fig. 3b). The optical signal is drastically reduced when an optical fiber suddenly bends at the fracture (lower line, Fig. 3c). Cracks in the structure may be located using the time values on the OTDR record that correlate to sharp signal dips. Also, if a calibration relation is known, the crack opening may be determined from the size of the drop.

For the first time, a crack monitoring approach that does not need previous information of the fracture position has been suggested by Leung et al. (2000). In order for the sensor to function, the fracture direction must be determined. Crack detection requires the use of many sensors since a single "zigzag" fiber's data might be difficult to understand in areas where the fiber's direction varies (Leung et al. 2000).

Strain sensors

It is possible to either embed or adhere FOSs to various materials, such as concrete, steel bars, steel plates and fiber-reinforced polymer (FRP) strips. Structural performance monitoring has seen a number of papers on the use of FBG and FP sensors in recent years, and many of them are predicated on the capacity of FOSs to detect internal strain.

Measurement of multidimensional strain was accomplished using FP sensors by Grossman and Huang (1998). Using fiber optic strain sensors, Buonfiglio and Pascale (2003) conducted studies on concrete specimens. Small size of FOSs allowed them to measure internal strain states without altering the specimen's stress condition. When bending a reinforced concrete beam, multiplexing FBG sensors were utilized by Kenel et al. (2005) to monitor the stresses along the 10-mm diameter reinforcing bars implanted in the concrete. For large stresses and strain gradients, the sensors were shown to be accurate with high accuracy without changing the bond characteristics.

Reinforcement bars may have a significant impact on the health of a concrete structure. Strain measurements on reinforcing bars have been the subject of much investigation in recent years (Casas and Cruz 2003). An FBG strain sensor is shown in Fig. 4, which is attached to a piece of rebar. Sensor zone is attached to polished fibers, thus the fiber's outer jacket is only removed from the sensor area.

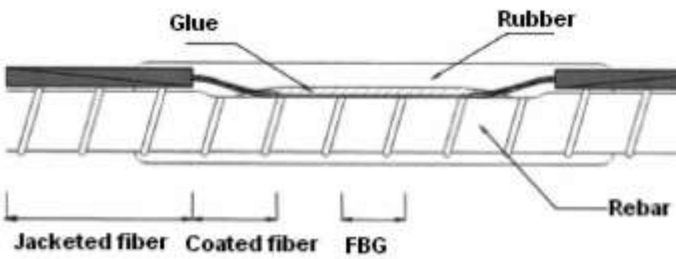

Fig. 4 Scheme of the fiber Bragg grating strain sensor (Casas and Cruz 2003)

Cyanoacrylate is applied to the rebar's surface. In addition to the fiber jackets protecting the input/output leads, rubber is used to protect the sensors.

Civil infrastructures that have been subjected to heavy loads, age, and chemical assault by deicing salts are increasingly being repaired using FRP sheets, laminates, and plates, which have recently become more popular. Recent years have seen a lot of attention and study towards the integration of FOSs with these sophisticated composite materials. It was found that fiber optic strain sensors mounted to the carbon fiber-reinforced polymer (CFRP) plates used to reinforce concrete constructions performed well. The FOS strain data were compared to the electrical strain gauge values that were also collected (ESGs). Using FOSs, the researchers found that they could reliably get accurate strain measurements below 4000 (the discrepancy between the FOS and ESG values was always less than 5 percent) with little or no effect from load amplitude or fatigue cycle count for strains less than 3300. A wide range of loading conditions, load range, and number of fatigue cycles proved that FOSs could accurately measure stresses.

Conclusion

FOSs and their applications to civil infrastructure structural monitoring are reviewed in this work. The FBG sensor and the FP sensor, two frequently used FOSs, were examined. Both sensors can measure strain and identify fractures and corrosion. Finally, it can be stated that fiber optic sensors can be utilized to accurately measure structures and quantify the number of parameters. These sensors are also used for non-destructive testing of the members under long-term service loads, with the capacity to warn of approaching failure. In general, fiber optic sensors exhibit great sensitivity and accuracy in the measurement of average strain, stress, and temperature in a variety of constructions. A further benefit of fiber optic sensors is that they may be positioned in any direction you choose thanks to their flexibility and adjustability. However, more laboratory and on-site testing investigations are required.

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