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APPLICATION OF OPTICAL FIBER IN MAGNETIC RESONANCE

Dr. Ajay Rana*; Dr. Shiva Sharma**

*Shobhit Institute of Engineering and Technology,
(Deemed to be University), Meerut, INDIA
Email id: ajay.rana@shobhituniversity.ac.in,

**School of Biomedical Engineering,
Faculty of Engineering and Technology,
Shobhit Institute of Engineering and Technology,
(Deemed to be University), Meerut, INDIA
Email id: shiva@shobhituniversity.ac.in

ABSTRACT

Due to a rising need for applications in medicine, Magnetic Resonance (MR)—compatible sensors based on various methods have been developed during the past several decades. There are a number of technical options for creating MR-compatible sensors, but the one based on optical fibers has a number of advantages. The high elasticity and small size allow miniaturized fiber optic sensors (FOS) to be designed with metrological characteristics (e.g., accuracy, sensitivity, zero drift, and frequency response) suitable for most common medical applications; the immunity to electromagnetic interference and the lack of an electrical connection to the patient make FOS suitable for use in high electromagnetic fields. These two characteristics increased the potential function of FOS in medicine, making them particularly appealing for use in MRI. This article gives an overview of MR-compatible FOS, with an emphasis on the sensors used in medicine to measure physical characteristics (i.e., temperature, force, torque, strain, and position). The operating principles of the most promising FOS are examined in terms of their respective benefits and drawbacks, as well as their medical applications.

KEYWORDS: *Fiber Optic Sensors, Fiber Bragg Grating MR-Compatibility, MRI Interferometry, Sensor.*

1. INTRODUCTION

Magnetic resonance imaging (MRI) is a radiological imaging method that creates images of the body's architecture and physiological processes. Strong magnetic fields, magnetic field gradients, and radio waves are used in MRI scanners to create pictures of the body's organs. MRI scans do not utilize X-rays or ionizing radiation, which sets them apart from CT and PET scans. MRI is a kind of nuclear magnetic resonance (NMR) imaging technique that may also be utilized in other NMR applications, such as NMR spectroscopy. For medical diagnosis, staging, and follow-up of illness, MRI is extensively utilized in hospitals and clinics[1]. MRI pictures of soft-tissues, such as the brain or belly, have greater contrast than CT images. However, since the measures are typically longer and noisier with the subject in a long, restricting tube, it may be regarded as less pleasant by patients. Implants and other non-removable metal in the body may also represent a danger, preventing certain individuals from successfully having an MRI scan[2].

Historically, the earliest use of optical fibers in medicine was for the lighting of interior organs during endoscopic operations. Over time, the same technology has been used to accomplish various activities, including laser treatments and the development of transducers for monitoring parameters of interest for both therapeutic and diagnostic reasons. Despite the fact that Fiber Optic Sensors (FOS) have been around for forty years and have certain benefits over other established technologies, their market has only expanded significantly in the past decade, owing to improvements in essential optical components and lower prices[1]. FOS is now used to monitor a variety of chemical and physical characteristics of medical relevance. Intrinsic sensors, in which the optical fiber acts as a medium for conveying light whose characteristics (e.g. intensity, frequency, phase) are modulated by the measurand extrinsic sensors, in which the optical fiber acts as a medium for conveying light whose characteristics (e.g., intensity, frequency, phase) are modulated by the measurand [3]. The fundamental components of FOS (e.g., light source, photo detector) may be deployed distant from the sensing element in this second class of sensors, allowing for the development of compact sensors and hybrid systems. FOS is attractive for a variety of applications that take place inside or near the magnetic resonance scanner, in addition to the well-established applications in industrial and medical fields. Immunity from electromagnetic interferences, combined with good metrological characteristics and small size, make FOS attractive for a variety of applications that take place inside or near the magnetic resonance scanner[2].

Magnetic Resonance Imaging (MRI) has grown in significance in clinical imaging since its debut in the early 1970s, exceeding even the most hopeful expectations of researchers. The increasing number of exams based on this method, as well as the introduction of novel procedures in clinical practice that are conducted under MRI supervision, has prompted research into new sensors that may be used in this situation. FOS is one of the MR-compatible applications that may be used to enhance surgical operation results as well as patient monitoring. The temperature of patients undergoing MRI-guided hyperthermia treatments, the evaluation of deflection and force on needles during MRI-guided operations and the estimate of physiological parameters (e.g., heart rate and breathing monitoring) are all examples of those uses. There are many applications for such sensors in research procedures. The ASTM standard F2503 addresses MR safety issues including the usage of equipment in the MR environment. There are three categories in the standard: "MR safe," "MR conditional," and "MR unsafe." “MR-safe” refers to an item that poses no known hazards in all MR environments; “MR-conditional” refers to an item that has been shown to pose no known hazards in a specific MR environment under specific use conditions; and “MR-unsafe” refers to an item that poses known hazards in all MR environments. Despite the fact that the ASTM F04.15.11 MR Standards subcommittee agreed to drop the phrase "MR compatible," it is still widely used in medical and technical practice. It is critical to distinguish between the phrases "MR-safety" and "MR-compatibility"[3]. MR compatible means that a gadget is “MR safe” when used in an MR environment and has been tested. It has not been shown to have a major impact on the quality of diagnostic information, nor has it been shown to have a substantial impact on the quality of diagnostic information. The MR device has an impact on operations.

Fiber optic technology is especially well suited to developing “MR-compatible” sensors in this light. Because of its tolerance to electromagnetic forces, it can: (1) be safe; (2) not degrade picture quality. (3) Ensuring that the sensors' functionality is not harmed. Furthermore, the material that was utilized to construct the. Magnetic fields within the MR-scanner are not perturbed by optical fibers, which is a critical element for the scanner's performance. The preservation of diagnostic information's quality. This article gives an overview of “MR-compatible” FOS, with a particular emphasis on sensors. Used to measure temperature, force, torque, strain, and position throughout a variety of medical procedures procedures[4]. Throughout the article, we provide a critical assessment of the most promising and widely used technologies. techniques. We divided them into three categories for clarity's sake: I Fiber-based FOS Bragg on grating technology; (ii) FOS based on intensity; (iii) FOS based on interferometric methods. Moreover, the fundamentals of measurement, potential medical uses, and benefits and disadvantages of each technique are discussed.

1.1 Working Principle:

Temperature and strain may be sensed using MR-compatible sensors based on fiber Bragg grating (FBG) technology, which have been developed in a variety of configurations. Hill et al. utilized electromagnetic waves to locally alter the refractive index of the optical fiber core, which led to the development of the FBG in the area of thermal and mechanical measurements. Meltz et alwork, [5]. published 10 years later, aided the spread of FBGs by describing a more successful, holographic method for grating creation. FBGs have been used in a variety of areas, including telecommunications and the design of FOS, because to the features of photosensitivity technology and its natural compatibility with optical fibers. Despite the FBG sensors' many advantages, their widespread use was hampered by their high cost and production challenges, which were finally solved in the 1990s. Several research groups have developed sensors based on FBG in the past decade. Different studies provide detailed descriptions of the properties of these sensors, their manufacturing method, and their medical uses[6]. The working concept of an FBG is based on radiation reflection produced by the Bragg grating: when a fiber optic containing an FBG is probed with polychromatic radiation, the FBG only reflects a limited range of wavelengths. As a function of the effective refraction index of the core (eff) and the spatial period of the grating, the center wavelength of such a range, termed Bragg wavelength, may be written as follows:Temperature and strain affect and eff, allowing sensors to be designed to detect temperature and strain, as well as other physical characteristics linked to them (e.g., pressure, force, vibrations, and flow).

For FBG-based transducers, certain solutions may be used to make them selectively responsive to strain or temperature. A reference FBG is usually added to the primary sensor to reduce the impact of unwanted effects and improve the measuring system's repeatability. Sensors with excellent metrological properties, such as good precision, wide bandwidth, big dynamic range, and high strain and temperature sensitivity (typical values range from 0.64 pm/ to 1.2 pm/°C, and 6.8 pm/°C to 13 pm/°C, respectively) may be developed using FBG technology. Furthermore, since several gratings with different Bragg wavelengths may be written on a single fiber, this technique allows for multiplexing. On the other hand, in order to prevent a reduction in performance (e.g., resolution and accuracy), the measurement chain should use a costly equipment to identify the wavelength of reflected light (i.e., an optical spectrum analyzer).Finally, interferometric methods such as the Sagnac, Fabry-Perot, and Michelson interferometers may be used to implement Fiber Optical Fiber (FOS) . Both intrinsic and extrinsic FOS may be developed using these methods. In the first instance, the fiber serves as a conduit for radiation that is modulated by a detecting device at the fiber's tip. In the second, the fiber itself acts as a sensor element, causing interferences that are modified by the measurand. Fabry-Perot interferometry is the most frequent interferometric configuration used to create FOS. Its sensing method is based on two semi-reflective mirrors that partly transmit and partially reflect the light that travels through the fiber.

Electromagnetic waves interact constructively and destructively with themselves and generate fringes as a result of numerous reflections. The optical path, which is linked to the distance between the mirrors, determines the intensity of these fringes. As a result, these FOS may be utilized as supplementary elements to measure the factors that affect the distance between the two mirrors.

1.2 Medical Applications

Biocompatibility, broad bandwidth, and compact size are the key features that make FBG technology especially suited for medical applications. Furthermore, fiber optics' resilience to electromagnetic fields and low interference with the electromagnetic fields utilized in MRI make this technology appealing for creating “MR-compatible” sensors. Some research groups have suggested FBG-based sensors for monitoring temperature in MRI, which is critical for a variety of applications: for example, Rao and colleagues created a cardiac output estimate measurement chain with a resolution of 0.2 °C and an accuracy of 0.8 °C. During MRI-guided hyperthermia treatments, this technique is also used to monitor tissue temperature. Temperature does play an important role during hyperthermia, and monitoring it may aid the physician in adjusting the heat exposure. The metrological performance of widely used temperature sensors, on the other hand, is influenced by the electromagnetic fields employed during the process to produce hyperthermia. To address this issue, Webb and colleagues developed a five-FBG measuring system that enables them to take temperature readings during hyperthermia therapy of the kidney and liver in live rabbits.

Other researchers investigated the possibility of employing FBGs to monitor temperature in hyperthermic swine pancreatic tissue. In a subsequent study, the same authors measured tissue temperature using 12 small size FBGs (1 mm length) in an attempt to improve spatial resolution, and used an ad hoc designed MR-compatible polymethylmethacrylate (PMMA) mask to precisely arrange the optical applicator and the FBGs inside the tissue. This technique has also been utilized to monitor temperature during prostate cryosurgery and liver cryosurgery, where the MRI compatibility was tested experimentally.The monitoring of strain and other associated parameters is the second use of FBGs in MRI. Several research has focused on using FBG sensors to measure ventilatory movement and respiratory rate during the past decade. Witt and Colleagues suggested a system with various FOS and an FBG-based sensor to detect thorax circumference changes for monitoring respiratory motions. De Jonckheere and colleagues developed two MR-compatible sensors for capturing thoracic and abdominal motions in sedated patients during MRI examinations for a similar purpose. Because of their great sensitivity to strain, they used an FBG-based sensor implanted in an elastic bandage to monitor thoracic motions. Grillet et al. developed three sensors for respiratory monitoring in an MRI setting, one of which is based on FBG. Silva et al., who used FBG sensors to monitor both respiratory and heart rate. who evaluated the feasibility of employing FBG sensors for respiratory monitoring and cardiac activity within a 1.5 T MRI scanner , used a similar method[7]. Large amounts of study have recently been dedicated to the use of FBG sensors in minimally invasive surgery. The FBG sensors are helpful in this situation to give feedback on the force exerted to the patient's tissue in order to prevent injuring tissues during the application of surgical knots.

With a resolution of 0.1 N, a measurement error of less than 0.1 N, and a measurement range of up to 10 N, Song and colleagues created a flexible and sterilizable FBG force sensor system for minimally invasive robotic surgery[8]. Iordachita and colleagues developed a force measuring system for retinal microsurgery that allows for 0.25 mN resolution in estimating contact forces at the tool tip. reported the development of a small FBG sensor (15 mm in diameter and 20 mm in height) to give force/torque feedback during robot-assisted prostate surgery. This can measure axial force with 0.1 N precision ranging from 20 N to 20 N, and torque with 1 Nmm resolution ranging from 200 NM to 200 NM. Three FBG sensors were used by Park and colleagues to detect needle deflection during MRI-guided operations.

2. LITERATURE REVIEW

J. Ballato[3]Propose that The goal of this article is to examine the current state of the art in optical fiber pressure sensors for medical applications. Because of their compact size, electromagnetic interference immunity, and adaptability for remote monitoring and multiplexing, optical fibers offer intrinsic benefits. Optical fiber-based pressure sensors are minimally invasive for many medical applications, as well as lightweight and flexible, making them ideal for in vivo monitoring. This implies that the sensor may be put directly within a patient for purposes such as urodynamic and cardiovascular monitoring. With specific reference to these application areas, this article provides an overview of current advances in optical fiber-based pressure measurements.

K. Kong[9] Propose that Raman spectroscopy is an optical method that uses inelastic light scattering by vibrating molecules to identify chemical fingerprints in cells, tissues, and biofluids. The ability to use advanced optical technologies in the visible or near-infrared spectral range (lasers, microscopes, fiber-optics) has recently led to an increase in medical diagnostic applications of Raman spectroscopy due to its high chemical specificity, minimal or no sample preparation, and the ability to use advanced optical technologies in the visible or near-infrared spectral range (lasers, microscopes, fiber-optics). Raman spectroscopy can identify and quantify molecular changes in cells, tissues, or biofluids that are either the cause or the consequence of illnesses, according to the central premise of this area. Multivariate calibration and classification models based on Raman spectra may also be built on huge "training" datasets and then used to fresh patient samples to achieve quantitative and objective diagnosis. Spontaneous Raman spectroscopy has a reputation for being a low-signal method that requires lengthy acquisition periods.

T. Abitbol[10] Propose that Because of its renewable nature, anisotropic form, outstanding mechanical characteristics, high biocompatibility, tailorable surface chemistry, and intriguing optical features, nanocellulose is gaining popularity in the areas of material science and biomedical engineering. Photonics, films and foams, surface alterations, nanocomposites, and medical devices are some of the major topics of nanocellulose research discussed. Nanocellulose fibers offer enormous promise in a variety of applications, ranging from flexible optoelectronics to tissue regeneration scaffolds. We want to share some of the current enthusiasm around nanocellulose research, which stems from the green nature of the particles, their intriguing physical and chemical characteristics, and the wide range of applications that this material may influence.

3. DISCUSSION

The advent of magnetic resonance imaging (MRI) is without a doubt the greatest significant milestone in biomedical research and treatment during the past two decades. To give you a sense of the social and economic consequences, the Organization for Economic Co-operation and Development (OECD) health data show that there are more than 20,000 MR scanners in OECD nations, and demand for high-field equipment (7 Tesla or higher) is growing globally.MRI has become a "can't do without tool" in medical disciplines such as cardiology, surgery,orthopedics, and neurology, owing to its capacity to examine and distinguish soft tissues. Furthermore, MRI's great spatial resolution, along with its ability to acquire functional characteristics of the investigated tissue indirectly, make it essential for investigating organ functions and imaging-guided invasive treatment. In the aforementioned situation, the need for "MR-compatible" sensors that can monitor physical parameters within the scanner and offer real-time feedback on the patient's condition and/or the impact surgical operations have on tissue is rapidly increasing. We evaluated the most promising work concepts used to develop “MR-compatible” sensors using optical fiber technology in this article. Transducers created for measuring temperature, force, torque, strain, and position received specific attention, with an emphasis on their operating principles, benefits and disadvantages, and medical applications. We divided the “MR-compatible” sensors into three groups based on their operating principle, using a variety of categorization criteria.

FBG sensors, intensity-based sensors, and interferometry-based sensors are the three types of sensors. For two primary objectives, “MR-compatible” sensors based on FBG technology have been used. For starters, they provide real-time monitoring of critical parameters during therapeutic invasive operations, resulting in better procedure results. Examples of such applications include: I tissue temperature assessment and control during hyperthermia or cryoablation done under MRI guidance; and (ii) monitoring of needle deflection and/or force used during MRI-guided treatments. Second, FBG has been used to track physiological characteristics that are of interest (e.g., respiration and heart rate). For comparable purposes, interferometric and intensity-based FOS have been used. Intensity-based FOS have several drawbacks, including undesired drift caused by variations in light intensity and bending losses; on the other hand, their measurement chain is simple and inexpensive. As a result, they are appropriate for a variety of medical applications that do not need precise metrology, such as respiration rate monitoring. The usage of FBG sensors provides for improved sensitivity and resolution, as well as multipoint measurements, and they are unaffected by variations in input light intensity, despite the fact that they need an optical spectrum analyzer, which is a costly and large instrument. As a result, when high performance is critical to improving the operation outcome, FBG technology is suggested (e.g., needle deflection in microsurgery). the lack of an electrical connection with the patient, and the small diameter of fiber optics are significant advantages over conventional transducers that drive the market growth of this technology (for example, FISO Technologies inc. and Camino Laboratories Inc. manufacture pressure and temperature sensors for medical applications). FOS is also an excellent option for meeting the increasing need for MR-compatible sensors because to its resilience to electromagnetic fields. Ad hoc developed FOS for medical applications has been commercially accessible in recent years; for example, Micron or Inc. and Opsense Inc. provide MR-compatible FOS for displacement, temperature, and pressure monitoring**.**

4. CONCLUSION

Finally, fiber optic sensor technology is a critical enabler for the creation of MRI-safe motion control systems, which are essential for modern medical research. Magnetic fields have no effect on fiber optic sensors since they are passive. Between the MRI Scanner (Zone 4) and the MRI Control/Equipment Rooms, optical fiber offers an excellent all-dielectric communication medium. MRI safe fiber optic sensors, made from the right materials, offer electromagnetic transparency for safe usage in and near the MRI Scanner's high electromagnetic field intensity. Even when utilized within the MRI bore, they are durable, simple to install, and do not produce artifacts or adversely impact imaging findings.

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