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REVIEW ARTICLE - ENGINEERING

Optical Sensor Implementation for Health Care Monitoring Based on Optical Fiber Technology: A Review

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Abstract

This study provides a review of the literature and an overview of optical fibers, as it is considered the highest class of intelligent materials, and there are many varieties and divisions based on the requirements of the manufacturer, it will review Optic Fiber Sensors (OFS) for measuring temperature and humidity. It has been divided into four main sections: The end user, and the environment. OFS Application in Healthcare, Impact OFS Qatar, Effect of chemical and mechanical properties of OFS Effect of external temperature changes in Surface Plasmon Resonance (SPR) for OFS Due to its unique characteristics, such as small size, lack of electromagnetic interference, high sensitivity, weights that allow sensing, accuracy, and very high dynamic range, it generates a fiber-optic sensor that is easy to manufacture and operate at the lowest possible cost. In addition, the development of Dispersive Sensor Systems (DSS) and OFS has found applications in both healthcare settings and strategies in biomedical research and structural Health Care Monitoring (HCM) to enhance the adoption of fiber-based medical equipment. Optics are two areas in which OFS has yet to realize its huge potential fully. The most recent published studies (2010-2023) were our main focus except for a few cases.

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Keywords: Dispersive Sensor Systems; Health Care Monitoring; Optical Fiber Sensors; Temperature; Humidity.

1. Introduction

The development of optical fiber sensors in medical applications has significantly increased. Fiber optic sensors (FOS) are used in invasive and non-invasive applications. It is electrically safe and can be placed in body cavities due to its non-galvanic nature and small size. Furthermore, FOSs resist electromagnetic disturbances caused by electrical devices (electro-surgery, radio communication, MRI). Sensors can be categorized into several application areas, such as in-vitro (for example, for the examination of gases, biological fluids, or tissue samples), In-vivo, by invasive methods (such as catheters or endoscopic apparatus): non-invasively in-vivo, using, for instance, optrodes put to the skin. In challenging conditions where electronics are impractical, such as practical MRI [1]. It is suitable for multiplexing numerous sensors per channel to build a sensor network since it can be utilized as a point sensor or in a spread sensor arrangement. Utilizing methods including intensity, polarization, phase, frequency, wavelength, and spectrum distribution, these could be used in a variety of intrinsic or extrinsic sensor modes to "probe" the properties of the light traveling in the optical fiber [2].

Being electrically safe, capable of remarkable size reduction, and capable of capturing nanoscales, it enables non-invasive investigation of biological matter at fairly deep penetration depths. Sensing components, such as optical fibers or optically transparently encapsulated photoacoustic and biochemical sensors, are often affordable and resistant to rust and water. Two fundamental strategies can be taken into consideration depending on how the fiber waveguide structure is to be optimized. In the first, an optical fiber of a specific type is used as a probe to modify the properties of the internal guiding wave. The second is to alter the waveform geometry by modifying the optical fiber structure specifically [3]. Since optical fiber has become so widely employed, common fiber topologies such as multimode fiber (MMF) and single-mode fiber (SMF) have been used to significantly reduce the cost of sensing systems. Special fabrication processes or doping materials, on the other hand, have produced a large number of particular fiber architectures with manufacturing qualities, a regulated mode, and simple integration [4] (such as hollow core fiber (HCF) [1], multi-core fiber (MCF) [2], photonic crystal fiber (PCF), polymer optical fiber (POF) [5]. Later, a growing number of fiber architectures, including the fiber grating structure [6], tapered optical fiber (TOF) [7], and D-shaped [6], have shown up on stage. Specialized appropriate optical fiber processing equipment is required to achieve these various optical fiber architectures.

Nomenclature & Symbols

CLC	Cholesteric Liquid Crystals Figure	LSPR	Localized Surface Plasmon Resonance
DCF-MZI	Dispersion Compensation Fiber Mach – Zehnder Interferometer	DSPRFS	Surface Plasmon Resonance Fiber Sensor with Dual Channels
MZI-SMF	Mach –Zehnder interferometer – Single-Mode Fiber	SMF-MZI	Single-Mode Fiber- Mach – Zehnder Interferometer
NCF-SPR	No-core Optical Fiber Sensor - Surface Plasmon Resonance	SPR-MZI	Surface Plasmon Resonance- Mach – Zehnder Interferometer
PCF-SPR	Photonic Crystal Fiber - Surface Plasmon Resonance	SEHADCF	A Segment of Single Eccentric Hole-Assistant Dual - Core Fiber
FBG-dip-coating	Fiber Bragg Grating –Dip-Coating	OFLPGs	Optical Fiber Long-Period Gratings
OFS	Sensor Optical Fiber	PCF-MI	Photonic Crystal Fiber-Michelson Interferometer
POF	Polymer–Optical Fiber	HCM	Health Care Monitoring
DSS	Dispersive Sensor Systems		

2. Related Work

Many researchers have studied the OFSs over the past few decades

2.1. Application of OFS in health care

R. Correia et al.,[8] assisted medical professionals in better understanding OFS technology, the authors focus on several forms of OFS and their applications in health care. The OFS is categorized by the standards used in healthcare, and this classification is either physical (such as temperature, pressure, or stress) or chemical (volatile organic compounds VOCs), making it the most suitable for medical applications. The important characteristics of OFS include non-interference with electromagnetic radiation, small size, and high sensitivity. Despite the advantages mentioned above, some disadvantages must be addressed when choosing the quality of fiber optic. Tapered optical fibers, for example, require careful packaging despite their high sensitivity and ease of production because the mechanical strength of the fiber is lowered during tapering, and they are difficult to employ in vivo, as shown in Fig. 1.

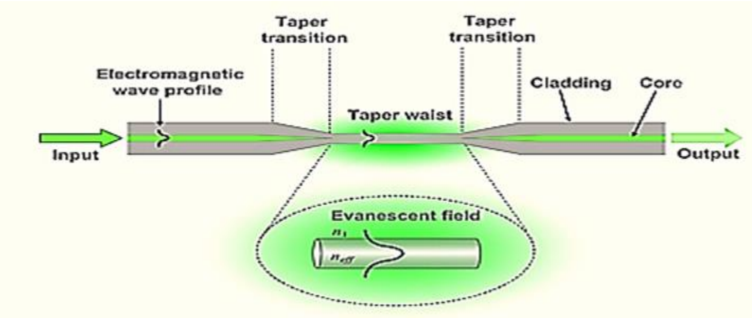

Fig. 1. A tapered optical fiber's structure is depicted schematically [8]

Wang et al. [9] designed a well-known tumor therapeutic technique that has emerged in recent years hyperthermia. Real-time body temperature monitoring equipment is necessary for tumor hyperthermia. The innovative Mach-Zehnder interferometer (MZI) based on single-mode fiber (SMF) is proposed in this paper and experimentally validated. The suggested sensor has an 8.962 nm/°C high-temperature sensitivity, as shown in Fig. 2.

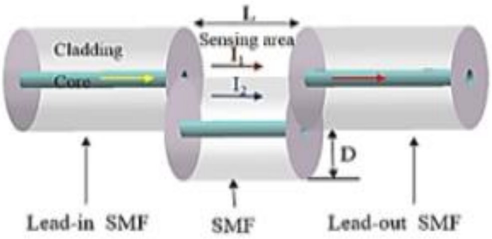

Fig. 2. The suggested sensor's proposed SSS structure [9]

2.2. The effect of OFS diameter

Dawood S. Ahmed et al., [10], the biomedical parameters (blood pressure, temperature, oxygen percentage in blood, heart pulse rate, etc.). The individual's physical and emotional state is reflected in these signals. As a result, measuring and monitoring those indicators is critical. So that the system is designed to utilize optical fiber technology based on the Mach-Zinder interferometer technology, and this is accomplished using two sensor diameters (125 and 60 mm). Chemical etching was used to minimize the diameter. When the diameter is reduced, the sensitivity rises by approximately five times. The outstanding qualities of optical fibers make them an excellent choice for a variety of applications, including medical domains.

S. Ahn et al.,[11] proposed CLC's helical axis to integrate vertically with the cross-sections of two optical fiber ferrules to create a CLC device. By utilizing this suggested CLC device based on optical fiber ferrules, an optical fiber temperature sensor has been developed. The sensor operates by employing a wideband wavelength-swept laser with a center wavelength of 1073 nm, a scanning range of 220 nm, and a reflection spectrum band that exhibits linear and reversible changes in wavelength variation. The variations in the reflection spectrum band, corresponding to the temperature fluctuations within the CLC cell, were measured. Fig. 3 demonstrates the outcomes, which vary depending on the temperature applied to the CLC cells.

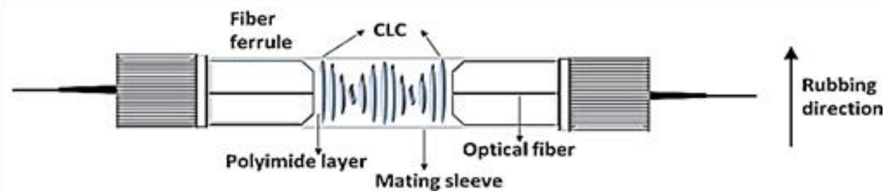

Fig. 3. Diagram of the manufactured CLC cell [11]

In Sharif et al., [12], the evanescence field effect of optical fiber for applications including humidity sensing was investigated in this experimental research. The "stripping method" was used to prepare the fiber optic such that it had a 125 diameter. The optical fiber is connected to the 1550 nm laser source on one end for sensing purposes and to the power meter on the other end for results viewing. The stripping area is then kept at a specific level of humidity inside the sealed container. Sensitivity, reproducibility, and linearity are among the criteria used to assess the sensor's performance.

2.3. The effect of chemical and mechanical properties of FOS

J. Hromadka et al.,[13] monitored temperature and relative humidity (R.H.) Variations in the air provided by a mechanical ventilator working in various modes have been proven for use in biomedical applications using an array of optical fiber long-period gratings (LPGs). The LPG array comprises two gratings, one of which has been modified with ten layers of silica nanoparticles to record relative humidity and the other of which has been left unchanged to measure temperature variations. Variations in temperature and relative humidity (R.H.) were caused by equipment. Using a planned sensor array, the sensor was successfully monitored, and its sensitivity was 0.46±0.01 nm/C°, and 0.53 nm/RH%, serially.

L. Liu et al.,[14] proposed the LSPR sensor described in this study, in which cotton-shaped dielectric metal nanoparticles excite the distal end of an optical fiber. The change in R.I. caused by the interaction of water molecules with hydrophobic Nano-coatings (silica nanoparticles,20 nm) around gold Nanospheres is used to assess relative humidity (R.H.) (40 nm). In the evaluated temperature range, the suggested sensor exhibits a quick response time and excellent accuracy without crosstalk measurement, and it is suitable for use in healthcare. The results show for the first time that a plasmonic hybridization excitation put on the tip of an optical fiber can increase the sensitivity0.63 nm/R.H% Fig. 4 depicts a wavelength-shift-based (LSPR RH) sensor.

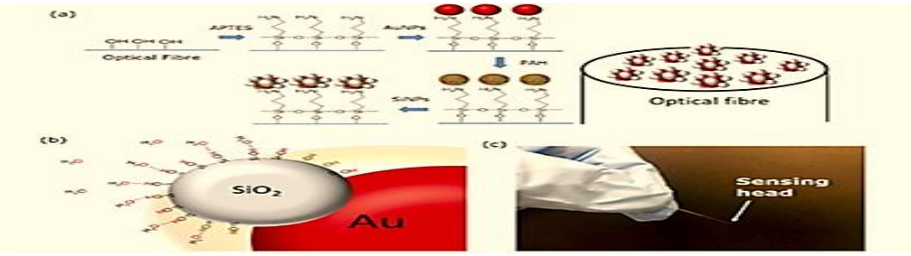

Fig. 4. (a) Diagram of an optical fiber's tip surface functionalization procedure, (b) The humidity sensing capability of the composite nanostructure is shown schematically, Note that the graphic only shows one type of hydrogen bonding, (c) A fiber sensor [14]

M.Li et al., [15], to detect creatinine in the human body, the authors proposed the design of a straightforward, transportable, and sensitive biosensor based on single-mode multimode fiber (SMF-MCF-MMF-SMF). The sensing probe diameter was using fiber-optic surface Plasmon resonance (LSPR). While E.W. is used to improve AuNP LSPR, two-dimensional (2D) materials (G.O. and MoS2-NPs) are utilized to improve biocompatibility, and C.A. is used to improve probe specificity. As a result, the excited mode is highly sensitive to changes in the MCF cladding environment, resulting in a supersensitive sensor that allows for rapid detection of creatinine levels in the human body, enables early detection and treatment, and reduces the risk of chronic kidney disease worsening, as illustrated in Fig. 5.

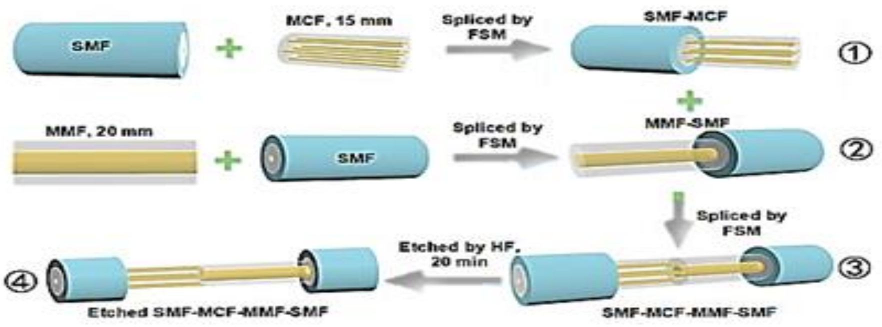

Fig. 5. Flow chart illustrating the manufacturing of a fiber structure made of SMF-MCF (1.5 cm)-MMF (2 cm) and a sensor structure based on SMF [15]

C. et al, [16], the intensity of reflected light is used by researchers; an optical fiber sensor has been developed for the simultaneous detection of temperature and relative humidity (R.H.) at a single optical fiber tip. Combining these measurements yields absolute humidity readings. The fiber tip is first given a coating of poly (allylamine hydrochloride) (PAH)/silica nanoparticles (SiO2 NPs) to determine relative humidity (R.H.). Thermochromic liquid crystal (TLC) is used to measure temperature. According to experimental results, the sensitivity to R.H. and temperature is 3.97 nm/C from 28 to 46 C (R2=0.973) and 0.43%/RH% (intensity at 650 nm) from 55 to 90% R.H. The recommended sensor also has little crosstalk between each of the sensing parameters, with reaction times of 3.1 s for temperature (30-38 C) and 13.2 s for relative humidity (20-80%). The proposed sensor outperforms optical fiber sensors based on gratings, is inexpensive, has a simple manufacturing procedure, and has the potential to be widely used in healthcare applications.

A. Leal-Junior et al.[17],The sensor, as illustrated in Fig. 6, is based on changes in the mechanical properties of fibers caused by changes in humidity and temperature. As a result, the researchers devised a system involving two POFs, each with predetermined torsional stress, and the effect of optical stress caused a change in the fiber's refractive index. Because there is a relationship between stress and material properties, variations in temperature and humidity create variations in fiber pressure, which causes variations in fiber refractive index. The sensor investigation is made up of merely two photodiodes. This results in a simple and low-cost device that measures temperatures ranging from 21 to 46C° and humidity levels ranging from 5 to 97%, for temperature and relative humidity readings.

In S. Chen et al.,[18], since flexible sensors are employed in a variety of applications, including electronic skin, intelligent robotics, and health monitoring, the researchers in this study used a direct drying process to create a noncontact flexible temperature sensor. During the COVID-19 epidemic, avoiding contact with public devices such as elevators, game consoles, and doors has been crucial because it can significantly lower the risk of transmission. Use poly (3,4-ethylene-dioxythiophene) and poly (4,6-styrene sulfonate) (PEDOT: PSS) as the elastomeric substrate and sensor material, respectively. The researchers considered temperature-responsive and the very sensitive PEDOT: PSS property. Has good hygroscopicity for printer paper. When utilized in noncontact sensing mode, the developed sensor displays excellent stability and high sensitivity in the temperature range of 20 to 50.

A. Leal-Junior et al.,[19], the goal of the researchers was to create a sensor with improved temperature sensitivity and reduced angular latency. The fibers have a hard time breaking down because of the low relative humidity. For comparison with the annealed samples, a third group of samples that had not undergone any heat treatment was used. These samples were submerged in both moisture and water. The fibers that were annealed under water displayed better temperature sensitivity and fewer mistakes than those that were annealed at low humidity or without heat treatment, according to the temperature and angle data. Fiber or unplasticized moisture. In addition, there was less lag in the angle characterization of the plastic fibers immersed in water. Because of these factors, a sensor system was created that can measure angle and temperature simultaneously using these fibers. And temperature, with an additional rms error of 2.20° for angle and 0.82° for temperature. After using the dynamic compensation technology of the POF curvature sensors, it was reduced to 1.20°, as shown in Fig. 7.

J. Mathew et al.,[20]. An optical relative humidity (R.H.) sensor with polymer infiltration and a fiber photonic crystal interferometer were the subjects of the study. With a shift in reflected power of 84% R.H., the sensor changes by around 12 dB, demonstrating its remarkable sensitivity to R.H. variations. The sensor is useful because it features an end-type probe structure that enables monitoring of humidity in microenvironments and a very tiny length of 1 mm. The repeatability, long-term stability, measurement precision, and temperature dependence of the sensor were all tested by the researchers. Because of its quick response time, the sensor can be utilized as a human respiration rate monitor in a clinical context, as displayed in Fig. 8.

S. Coyle et al.,[21], the BIOTEX project's researchers sought to develop tissue sensors that can evaluate physiological factors and the chemical makeup of bodily fluids, with a focus on sweat. The tissue-based fluid handling system for sample collection and transportation includes the construction of a wearable sensor system with sodium, conductivity, and pH sensors. In addition, sensors for respiration, sweating, and the electrocardiogram (ECG) were developed. For the first time, multiple physiological signs can now be observed simultaneously. A fiber-optic sensor for measuring moisture. This film was produced by the sol-gel method and dipped to affix it to the end of an optical fiber. The sensor reaction time might range from 10 seconds to less than 2 minutes to evaluate the analytical sensor's response without being impeded by ambient gases or vapors.

B.Li et al., [22], the scientists suggested a direct, two-channel fiber optic SPR sensor that could gauge both glucose levels and ambient temperature. This is because fluctuations in the ambient temperature have an impact on the SPR optical fiber sensor's accuracy. The suggested sensor is a two-channel, non-central optical fiber (NCF)-the based device with one channel coated in a silver film for measuring glucose concentration and the other in a gold and polydimethyl film. Temperature sensor made of siloxane (PDMS). The sensor is sensitive to temperature (-2.904 nm/°°C) and glucose concentration (2.882 nm/%, respectively), according to the experimental results. Keeping track of the present temperature improved the precision of glucose concentration detection. Due to its simple and compact shape, the suggested sensor is suitable for sensing glucose solution or other analyte solutions that require temperature adjustment, as seen in Fig. 9.

Y. Wang et al.,[23], The researchers conducted an evaluation and experimental demonstration of a highly sensitive humidity sensor using a Fabry-Perot series interferometer to induce the Vernier effect, which amplifies the sensor's response. The construction of the sensor involved attaching a capillary section to a single-mode optical fiber and immersing the capillary in a polyimide (P.I.) solution to create a P.I. film. The experimental results revealed that within the range of 40-85% relative humidity, the sensitivity of the sensor's spectral envelope could reach 344.4 m/% R.H., which is 3.77 times higher than that of the sensor's staggered edge. Theoretical methods and experimental findings are in essential agreement. The sensor is straightforward to construct and can be easily replicated, offering excellent sensitivity to humidity.

In L.Liang et al., [24] the authors proposed and experimentally showed the capability of a very sensitive optical fiber relative humidity sensor probe to calibrate temperature. It is comprised of a direct Fabry-Perot interferometer made by covering the end face of a single-mode fiber with a thin polyimide (P.I.) sheet and an upstream Bragg fiber (FBG) grid. PI is an organic polymer with good all-around properties that is sensitive to moisture. Experimental results show that the sensing probe can monitor temperature and R.H. concurrently 986.25 pm/% R.H. is the maximal R.H. response sensitivity. Due to its advantages of a basic structure, compact size, high sensitivity, simple packing, and dual-parameter measurement. This sensing probe offers a wide range of potential applications, as depicted in Fig. 10.

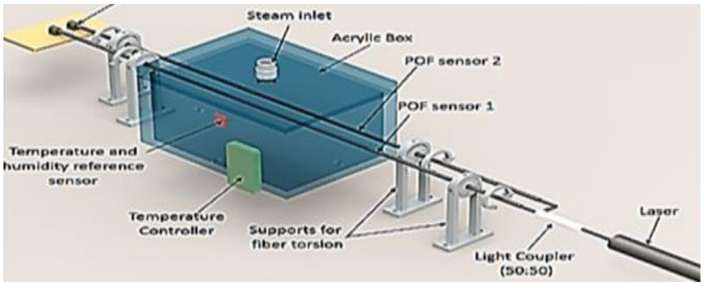

Fig. 6. Setting up an experiment to evaluate POF temperature and humidity sensors [17]

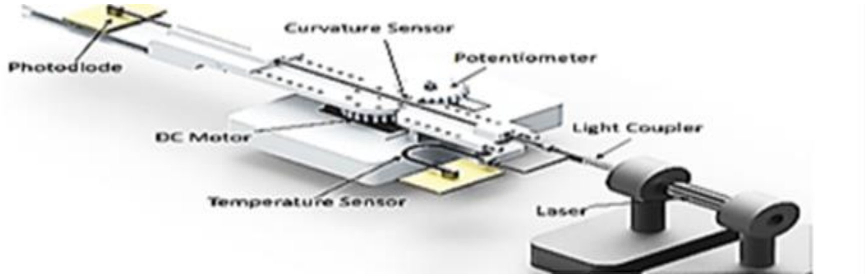

Fig. 7. Experimental setup for POF sensors to measure angle and temperature [19]

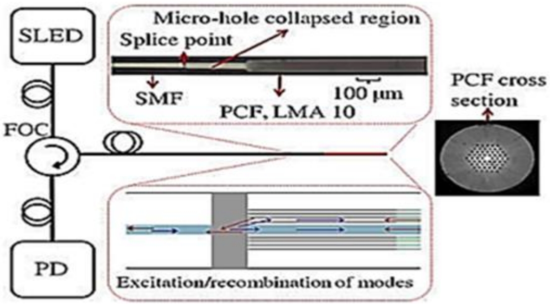

Fig. 8. Schematic of the humidity sensor system [20]

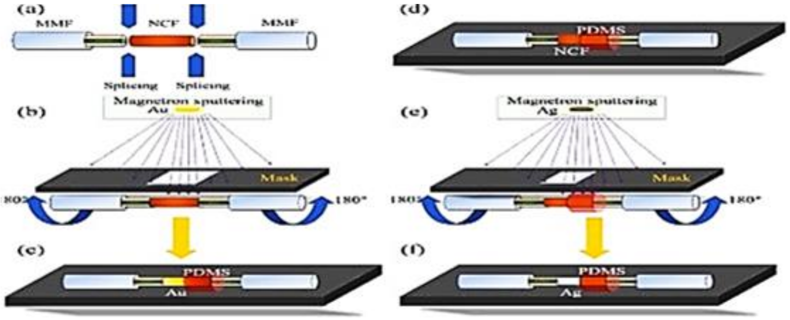

Fig. 9. Sensor fabrication process [22]

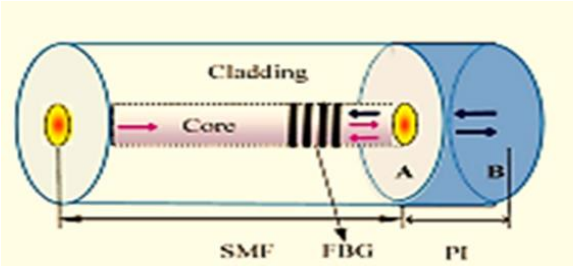

Fig. 10. Schematic representation of the probe [24]

B. Du et al.,[25], the researchers show how an etched single-mode fiber (ESMF) coated with MoS2 can be used as a moisture sensor. The interaction between MoS nanosheets and the evanescent field generated by the ESMF enables the control of light confined within the fiber core based on surrounding environmental conditions. This visual effect allows for real-time detection of human breathing due to the sensor's rapid response (0.066 seconds) and recovery (2.395 seconds) times. The results also indicate that the sensor is capable of tracking different breathing patterns, including variations in breathing depth and frequency. Fig. 11 provides a visual representation of these findings

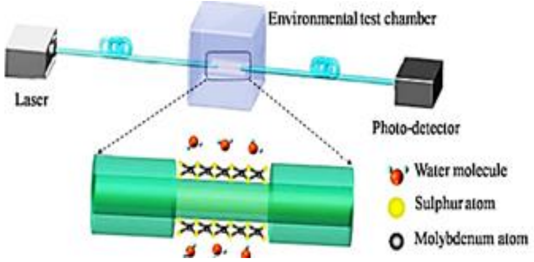

Fig. 11. Sensing relative humidity in an experimental setting [25]

C.-S.Chu et al.,[26], Researchers have discovered a simple and cost-effective method to construct a plastic optical fiber sensor capable of simultaneously sensing temperature and oxygen. In this dual-sensor design, the temperature and oxygen indicators are enclosed at the end of the fiber. The sensing components consist of platinum pentrafluorophenyl tetrachloride (PtTFPP) and 5(6)-carboxyfluorescein(C.F.) embedded in a permeated fluorinated xerogel. The study's findings demonstrate that the fluorescence properties of the temperature sensor remain unaffected by the presence of the oxygen sensor. Furthermore, the temperature sensor exhibits an exceptionally accurate linear response within the temperature range of 25-66°C. The dual optical fiber sensor for noncontact temperature monitoring and oxygen sensing systems can be used for temperature compensation in biological, medicinal, and environmental applications in addition to oxygen sensing.

G.Yan et al., [27], Researchers developed and experimentally validated a novel high-performance fiber-optic sensor based on Bragg's fiber grating (FBG) for simultaneous measurement of relative humidity (R.H.) and temperature. The FBG follows a taper with a nodular shape that serves as a multi-purpose joint that excites and couples back into the leading single-mode fibers mirrored by the FBG's cladding modes. A polyvinyl alcohol (PVA) layer is dipped on the surface of the fibers and alters the intensities of the cladding modes employing ephemeral fields as a moisture-to-refractive index (R.I.) converter. By measuring the strength and wavelength of the reflected cladding patterns, the change in relative humidity and temperature may be estimated simultaneously. The experimental results revealed an R.H. sensitivity of up to 1.2 dB/% R.H. in the R.H. range of 30-95%, which is significantly greater than previously reported values. Additionally, throughout the range of 25-60C, the temperature sensitivity of 8.2 PM/C can be attained. Due to its ability to concurrently measure relative humidity and temperature, quick response time, reusability, and simple production technique, this device is a very promising sensor for real-time R.H. monitoring applications. Displayed at Fig. 12.

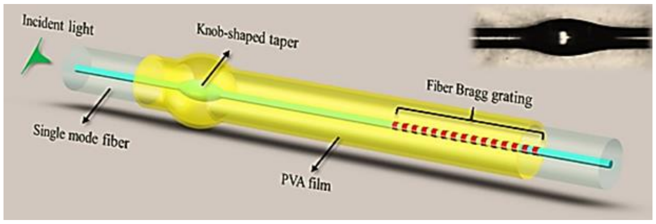

Fig. 12. The schematic representation of our suggested sensor structure, the manufactured knob-shaped taper's optical microscope image is shown in the inset [27]

F. U. Hernandez et al., [28], a small device that can detect moisture in ventilator care kits has been developed by researchers. A porous film made of alternating layers of allylamine hydrochloride (PAH) and silica (SiO_2) nanoparticles was applied to the optical fiber. With the absorption of water vapor, the optical thickness varies, which causes a change in reflectance that changes proportionally to humidity. For testing sensitivity and response times, nine bilayers at a maximum were used in the relative humidity (R.H.) range of 5% to 95%. Results As more bilayers are deposited, sensitivity rises; nine bilayers produced a sensitivity of 2.28 mV/%RH. It took 1.13 seconds and 0.30 seconds to respond, which is quicker than the commercial device's 158-second measurement. Finally, fiber-optic sensors can be utilized to monitor a patient's breath humidity while administering ventilator therapy. The created sensor offers a precise, portable, and quick way to detect humidity.

J. Yang et al.,[36], the researchers tested a relative humidity (R.H.) sensor based on a directional coupler inside a fiber. A section of single-mode eccentric-hole dual-core fibers (SEHADCF) is directly spliced between single-mode fibers (SMFs) to create a fiber directional coupler (IFDC), the gelatin acts as a moisture-sensitive material and is coated over the exposed suspended core to create the suspended core coating. The experimental measurements of the IFDC temperature sensitivity and stability are also carried out, with the mean and maximum R.H. sensitivities being 7.005 nm/% R.H. and 18.94 nm/% R.H., respectively, in the 70%-90% R.H. range. Due to its incredibly high sensitivity and low-temperature interference, the suggested sensor is anticipated to be a promising choice for highly sensitive relative humidity detection applications in high-humidity conditions as seen in Fig. 13.

Fig. 13. RH sensor based on SEHADC-IFDC schematic diagram, the SEHADCF's cross-section is shown inset [36]

S.L. Khashin et al.,[30], in this study, the researchers assess the relative humidity (RH) using optical fibers using Fabry-Perot (F.P.) technology. To create the striped F.P. cavities, a 50 mm piece of non-core fiber (NCF) is chopped into single-mode fibers. The end side of the NCF is then covered with a thin polyvinyl alcohol (PVA) layer to serve as a mirror. Hydrofluoric acid (HF40%) was then used to reduce the NCF's diameter from 125 to 65 μm. The sensor is easy to make and displays great stability, as displayed in Fig. 14.

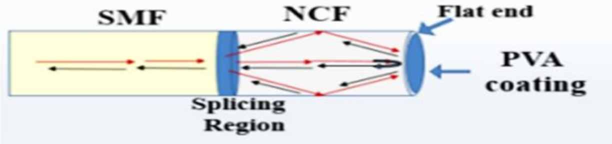

Fig. 14. Diagrammatic Representation of the HS-PVA Structure [30]

Y. Zhong et al.,[31], A fiber-optic interferometric humidity sensor interacted with a gelatin film via a short hollow core fiber (HCF) in this work. To produce a Fabry-Perot interferometer (FPI), a single-mode fiber (SMF) is linked to the end of a short length of HCF, which is then covered in gelatin. Since the thickness of the gelatin film affects the length of the interferometric cavity and, in turn, the dipping wavelength respectively, separated the response and recovery periods, good repeatability and stability were attained. With a sensitivity of 10 PM/C°, temperature could also be detected concurrently by an FBG sensor and an FPI probe. As seen in Fig. 15.

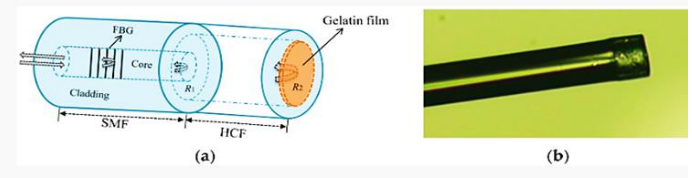

Fig. 15. (a) a proposed FPI humidity probe schematic, and (b) a picture [31]

2.4. The influence of changes in external temperature of SPR for OFS

S. Wu et al.,[28]. Surface plasmon resonance (SPR) biosensors' accuracy is impacted by variations in ambient temperature. The researchers suggested an ultra-compact, label-free, dual-channel SPR fiber sensor (DSPRFS) that can assess both the surrounding temperature and glucose level at the same time. By drilling side hole fiber (SHF), the new two-channel structure supporting the desired sensor was built. According to the experimental findings, the temperature sensitivity and sensitivity to glucose concentration are both extremely high at 6.156 nm/mm and -1.604 nm/C°, respectively. Temperature and glucose concentration LODs are 16.24 μM and 0.06 C°, respectively, as seen in Fig. 16.

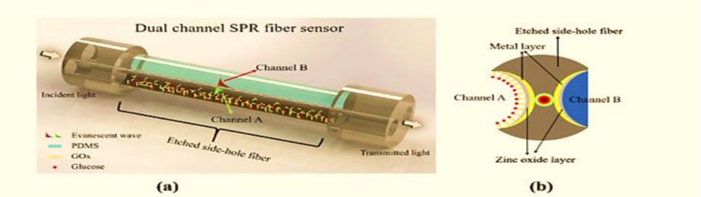

Fig. 16. (a) The dual-channel SPR fiber sensor schematic is illustrated, and (b) The etched side-hole fiber sensing area is shown in the cross-section [28]

P.Gong et al.,[29], the researchers have developed a highly sensitive, temperature-compensated fiber-optic DNA hybridization sensor by combining surface plasmon resonance (SPR)with Mach-Zehnder interference (MZI). This novel sensor achieves the simultaneous measurement of temperature and refractive index (R.I.) parameters using a simple single-mode fiber (SMF)- no core fiber (NCF) -SMF configuration, which is a significant advancement. The experimental results indicate that the R.I. sensitivities of MZI and SPR were 930 and 1899 nm/RIU, respectively, while the temperature sensitivities were 0.4 and 1.4 nm/C, respectively. Fig. 17 provides a visual representation of these findings.

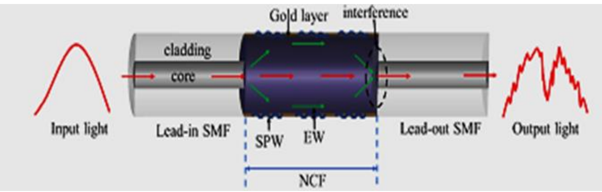

Fig. 17. The SPR and MZI hybrid optical fiber sensors are depicted in a schematic diagram [29]

F.Wang et al., [34], based on a tapered dispersion compensation fiber (DCF) structure, the researchers demonstrated a very sensitive sensor for detecting temperature and curvature. Single-mode fibers (SMFs) and a 6 mm DCF are sandwiched together to form this structure. The Mach-Zehnder interferometer (MZI) is introduced, and Taper action is used for the initial peg connection. In the experiment, changes in curvature had a very significant linear effect on the intensity of the interference dips, while temperature changes had a very strong cross-effect (0.0012 dB/C°). According to the results, the greatest bending sensitivity was up to 15.19 dB/m-1 within a linear range of 0.98-1.753㎡, and the temperature sensitivity was 79.8 m/C with a range of 25-60C°. Cross-resolving sensitivity was made possible by the observation of two separate measurements of sensitivity. The potential of the suggested sensor can be seen in its tiny size and high sensitivity. Applications include checking the structural health of buildings and issuing alerts, as seen in Fig. 18.

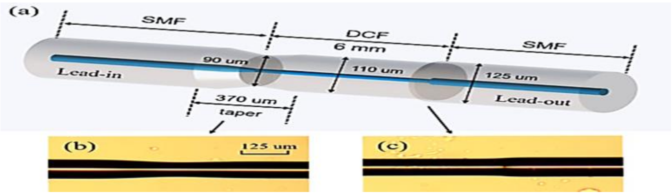

Fig. 18. (a) the SDTS sensor's schematic diagram, (b, and c) Optical microphotographs of the DCF to SMF splice and taper portions [34]

H.-M. Kim et al.,[37], the researchers took direct measurements with a surface Plasmon resonance-based photosensor. In addition to a quick thyroglobulin (Tg) assay. Specific Tg tests in individuals who have low sensitivity, complicated procedures, and in some situations, it takes a long time to receive results. This procedure for pain relief is precise, quick, and simple for the patient's physical and mental stress. A gold nanoparticle-encapsulated fiber-optic sensor was used to identify various Tg concentrations in a Microfluidic channel. In comparison to the real concentrations, the proposed sensor displayed a low error rate. Devices utilized in the healthcare field and sensors have many similarities. According to Tese's findings, our sensor can be a helpful tool for the early detection of thyroid cancer recurrence in patients who have undergone total thyroidectomy utilizing a sensitive and quick sensor, T.G., as seen in Fig. 19.

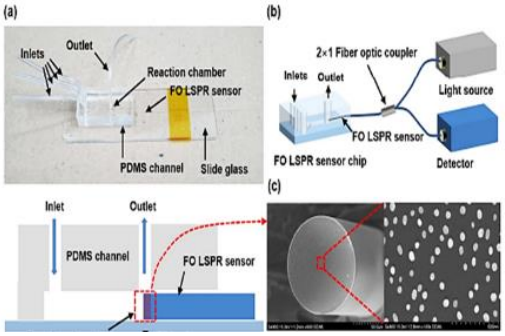

Fig. 19. FOLSPR sensor chip manufacture, optical setup, and sensor surface images Real-world photos of the sensor chip and its side view, an easy optical measurement setup, and FE-SEM images of an optical fiber end-facet with AuNPs [37]

M. Shao et al., [33]. Researchers develop a moisture sensor (PCF) made of polycrystalline optical fibers using these fibers, and ordinary single-mode fibers are laid by tapering. (SMF). A higher order results from the compressed and tapered region of the PCF. To create a Mickelson Interferometer (MI), combine them with the primary pattern. The experiment's findings demonstrate that the reflection's intensity of overlap changes linearly with humidity when used to detect human breathing. The sensor's high sensitivity, ease of manufacture, and quick signal response offer several possible uses. The experimental results detect motion; the sensor exhibits a low temperature as well as the presence of a high humidity level of 0.09% relative humidity/transversal sensitivity and a rapid response time, of 200 ms. Fig. 20 depicts this.

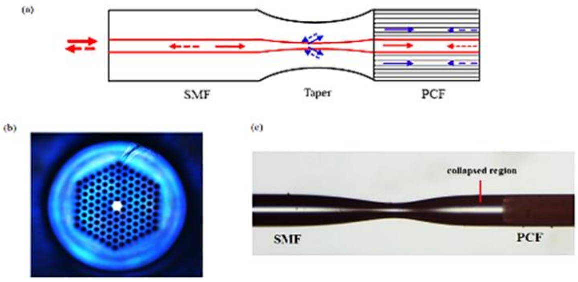

Fig. 20. (a, b, and c) A schematic illustration of the proposed humidity sensor, a cross-sectional view of the PCF, and a micrograph of the taper between the SMF and the PCF is shown in the images below [33]

S. Xiao et al.,[35], the researchers propose an MZI sensor within the fiber to separate temperature from stress. The sensor chute is two pieces of a typical single section. SMF with three taper peanuts, fiber mode. The cascading structure stimulates additional frequency components, resulting in additional interference dips in the transmission spectrum. Temperature and strain can be distinguished by comparing the wavelength shifts of two different spectral dips. The cascading SMF peanut taper is also a sturdy mechanical structure. As a result, the suggested sensor is a trustworthy, small, straightforward, and reasonably priced option for monitoring stress and temperature at the same time as shown in Fig. 21.

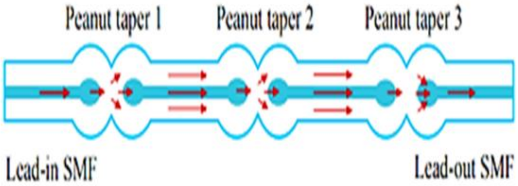

Fig. 21. The suggested sensor's structure is based on cascading single-mode fibers [35]

S. Gu et al.,[38], the scientists created a brand-new PCF-SPR sensor that uses two orthogonally polarized base modes (f) to simultaneously sense the magnetic field and temperature. Four tiny covered air holes for light transmission and construction are present in the proposed sensor. Four big circular microfluidic channels are evenly distributed outside the fiber structure, making setup and microfluidic flow easier. The upper and bottom microfluidic channels (also known as magnetic field channels) are filled with M.Fs, while the right and left channels (also known as temperature channels) are filled with temperature-sensitive materials. Because of the basic and SPR modes' coupling properties, these models can be employed individually to gather magnetic and temperature signals, and the improved sensor eliminates the problem of cross-sensitivity when detecting magnetic field and temperature. The temperature at the same time, which can be used in two-parameter sensing fields.

C. He et al., [39] Researchers used a fiber-optic localized surface Plasmon resonance (LSPR) sensor to find volatile organic molecules (volatile organic chemicals). Gold nanoparticles with a size of 40 nm are chemically adsorbed onto the tip of a multimode optical fiber to create the sensor, which is then functionalized layer by layer using the HKUST-1 metal-organic framework (MOF). At cycles 40,80, and 120, MOF-capped biosensors have reportedly been linked to various crystallization processes. The 40 coating cycles of the sensor exhibit no discernible response to the acetone, ethanol, or methanol-investigated volatile organic compounds. But when the number of coating cycles rises, sensors with 80 and 120 show noticeable resonant wavelength redshifts for all investigated VOCs (up to 9 nm). The HKUST-1 thin film's local refractive index rises as a result of VOC capture.

J.-K.Wang et al.,[40], Based on Plasmon resonance (SPR), this study proposed a D-shaped twin optical fiber temperature sensor. The finite element technique (FEM) is used to investigate the influence of varying coating thicknesses and polishing depths on sensor performance. Temperature and humidity were found to have very high sensitivity (2.9 nm/C° and 11.6 nm/C°, respectively). % R.H. ranging from 10-70℃to 20-80%RH [41]. This type of direct multi-parameter optical fiber sensor future development looks quite promising. Fig. 22 depicts this.

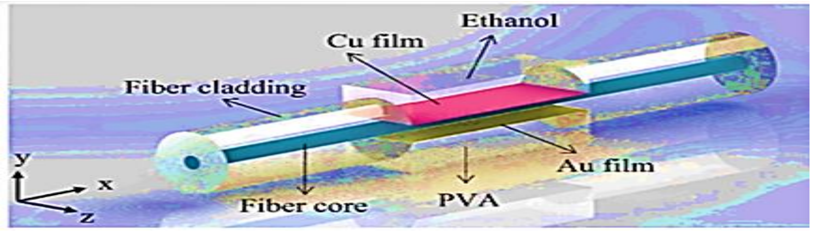

Fig. 22. The temperature and humidity sensor with a double D shape is shown schematically [40]

X. Zhou et al.,[42], to further emphasize SPR's superiority for temperature sensing applications, researchers theorized the creation of a unique SPR temperature sensor consisting of hollow fibers filled with liquid. The hollow fiber (HCF) used in this investigation has alcohol in the middle and a silver film covering its inner wall. The two multimode fiber (MMF) strips are then fused at the desired temperature. With a linear sensitivity of up to 1.16 nm/C° in the range of (35.5 to 70.1) C°, the designed sensor performed well in temperature sensing. This resulted from the optical coefficient of the alcohol This sensor's tiny size, excellent sensitivity, and low production cost make it perfect for measuring temperature during biological and chemical interactions. The possibility of multi-parameter or distributed temperature measurement is also provided, as displayed in Fig. 23.

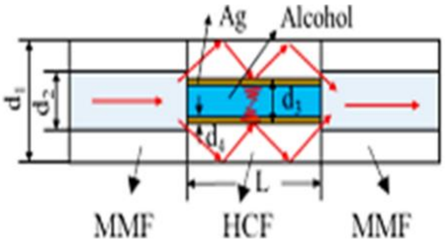

Fig. 23. Diagrammatic representation of the proposed temperature sensor [42]

In addition to these reviewed articles, a summary of the methods included in these fibers for calculating and comparing temperature sensitivity, as shown in Table 1, and calculating moisture sensitivity, as in Table 2 &3, was prepared.

Table 1. Comparing various temperatures fiber optic sensors

Method	Sensitivity Temperature	Detection Range	author	year	Ref
(MZI-SMF)	8.962nm/°c	33-43°c	Wang et al	2018	[9]
OFLPGs	-0.4±0.01nm/°c	-	Hromadka et al	2019	[13]
Layer-by-Layer	3.97nm/°c	28-46°c	Liu et al	2022	[14]
Young's and shear moduli POF	1.12/c°	21-46c°	Li et al	2021	[15]
POF	0.82/°c	-	Leal-Junior et al	2018	[17]
NCF-SPR	-2,904°c	-	Mathew et al	2011	[20]
FBG-dip-coating	0.82nm/°c	25-60°c	Du, et al	2017	[25]
DSPRFS	-1.60nm/°c	-	Wu, et al	2020	[28]
SPR-MZI	0.4nm/°c -1.4nm/°c	-	Gong, et al	2021	[29]
DCF-MZI	79.76pm/c°	25-60°c	Khashin, et al	2022	[30]
PCF-MI	0.005nm/c°	20-100°c	Shao, et al	2020	[33]
SMF-MZI	49.98pm/°c 60.52pm/°c	-	Xiao, et al	2023	[35]

PCF-SPR	-1410.7pm/°c	20-80°c	Yang, et al	2019	[36]
LSPR	Insensitive	25-40°c	Gu, et al	2022	[38]
LSPR	0.5±0.1nm/°c	20-25°c	He, et al	2021	[39]
SPR	2.9nm/°c	10-70°c	Wang,et al	2021	[40]
SPR	1.16nm/°c	35.5-70.1°c	Mohammed J. Sadiq et al	2022	[41]

Table 2. Comparison of different humidity optical fiber sensors

Method	Sensitivity humidity	Detection Range	author	year	Ref
OFLPGs	0.53nm/%RH	-	Hromadka,et al	2019	[13]
Layer-by-Layer	0.43nm/% R.H.	55-90%	Liu, et al	2022	[14]
Young's and shear moduli POF	1.36 nm/%RH	5-97%	Li, et al	2021	[15]
FPI	344.4pm/%RH	40-85%	Coyle, et al	2010	[21]
FBG-FPI	986.25 pm/%RH	-	Li,et al	2021	[22]
FBG-dip-coating	1.2db/%RH	30-95%	Du,et al	2017	[25]
Bilayers	2.28mv/%RH	5-95%	Chu,et al	2014	[26]
SEHADCF	-18.94nm/% R.H. -7.005nm/% R.H.	90%RH 70-90%RH	Yan, et al	2015	[27]
PCF-MI	-0.166db/%RH	30-90%RH	Shao, et al	2020	[33]
FRI	0.908nm/%RH	30-90%RH	Wang, et al	2021	[34]
FRI	0.192nm/% R.H.	20-80%RH	Kim, et al	2021	[37]
LSPR	0.63nm/% R.H.	-	Gu,et al	2022	[38]
LSPR	0.5±0.2nm/%RH	50-70%RH	He,et al	2021	[39]
SPR	11.6nm/%RH	20-80%RH	Wang,et al	2021	[40]

Table 3. Application

Ref	Year	Note
No.of refer/the year	2016/[26]	The findings show that it is possible to create a portable optical fiber humidity sensor that can be easily included in breathing circuits or ventilation masks.
No.of refer/the year	2017/[23]	During an MRI procedure, this sensor offers a secure method for quick breath monitoring of people.
No.of refer/the year	2021/[31]	When compared to a commercial kit, the sensor can identify thyroglobulin in the patient's serum with a high degree of accuracy.
No.of refer/the year	2021/[39]	Because it is not necessary to distinguish between types of VOCs, the suggested sensor has the potential to be used in monitoring VOCs in the workplace at first. In healthcare, it is employed in the analysis of respiratory gases.
No.of refer/the year	2023/[35]	Applications include temperature, strain, pressure, pH, humidity, curvature, magnetic field, and refractive index sensing.

3. Conclusion

The results of many investigations on the use of biosensors with unique fiber architectures have been accumulated, and there is much promise for industrial uses of optical fiber sensing technologies. They have applications and are getting cheaper all the time, and fiber optic sensors are also being created, mainly in chemical engineering, biomedical engineering, and materials. In associated preliminary work, the goal of OFS used in healthcare monitoring is to assist medical professionals with a better understanding of OFS technology. Because OFS is classified by standards for use in healthcare, its properties—such as its small size, lack of electromagnetic radiation interference, and high sensitivity—make it particularly ideal for use in medical applications. This classification may be either chemical (volatile organic compounds, volatile organic compounds) or physical (such as changes in temperature, pressure, or stress). The second section focuses the attention of the researchers on the effect of the diameter of the OFS, since the diameter is when it decreases, the sensitivity increases by about five times, and optical fibers are considered a good choice for a wide range of applications due to their outstanding properties, except health professions. , since cotton-shaped dielectric metal nanoparticles excite the distal end of the optical fiber, the authors focus on the influence of chemistry and mechanics on OFS. This is the focus of Section III. By combining this data, absolute humidity, and temperature values can be acquired at the end of a single optical wire. For instance, to measure relative humidity (R.H.), the fiber tip is first coated with poly (allylamine hydrochloride) (PAH)/silica nanoparticles (SiO_2 NPs): Chemical etching of the sensing probe diameter resulted in strong evanescent waves (E.Ws), which in turn produced a highly sensitive sensor. Lastly, the accuracy of the devices' OFS surface flour resonance (SPR) as a function of ambient temperature in the biosensor is impacted by variations in the surrounding temperature. A multi-purpose, extremely sensitive, and temperature-resistant fiber optic sensor requires: The researchers demonstrated a dual-channel SPR fiber (DSPRFS) that is extremely small and modulus-free. Future growth is anticipated. The area is currently attempting to transition from in-lab research to commercial applications, beginning with interdisciplinary academic fields and cutting-edge development ideas.

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