A Literature Survey on Smart Optical Fiber based Respiratory Monitoring system

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Abstract

Respiration is a significant physiological activity, and internet-based respiration monitoring is of utmost significance in clinical and wearable healthcare applications. Conventional respiratory sensors are actually so problematic that they induce distress, rigidity, signal distortion, and electromagnetic interference, especially in sensitive applications. To address such problems, the application of optical fiber sensors, namely plastic optical fiber (POF) sensors, has proven to be a highly viable solution since they are flexible, lightweight, and immune to electrical noise. They are integrated into wearable garments, elastic bands, and even hospitals requiring non-electrical solutions.

The current review provides a general overview of the different fiber-based respiratory sensing technologies, evaluating their structural geometries, sensing modes, and processing schemes. Smart textile advances, wave-structured fiber geometries, and low-cost fabrication of sensors are also addressed in this paper.

Keywords—*Fiber-optic sensor , Plastic optical fiber , Respiratory monitoring , Thermochromic pigment , Biomedical optics*

INTRODUCTION

Respiration is quite possibly one of the most fundamental physiological processes required to sustain life. It is the repeated inhalation of oxygen and exhalation of carbon dioxide, necessary for cellular metabolism and energy production. Respiratory rate (RR), or breaths per minute, is a significant parameter utilized in the assessment of the health of an individual. Normal adult RR ranges from 12 to 20 breaths/min, but it is age-dependent, activity- dependent, emotion-dependent, and illness-dependent. Diseases such as asthma, pneumonia, cardiac failure, COPD, and metabolic derangements are related to abnormal respiratory rates. Therefore, continuous and accurate monitoring of respiratory rate is important for early detection, clinical management, and postoperative care.

Historically, respiratory monitoring has been achieved through methods such as auscultation, impedance of the chest, capnography, thermistors, and strain gauges. They work generally by detecting chest movement, airflow temperature, or carbon dioxide concentration in exhaled air. Conventional sensors suffer from such shortcomings as bulkiness, discomfort with extended wear, sensitivity to motion artifact, and electromagnetic field interference—most annoying in environments such as MRI suites. In addition, they are not normally configured to run in the handheld or wearable mode, limiting their application to the home health market, the remote monitoring space, or for use in sport physiology.

As a solution for these limitations, scientists sought the fiber optic sensor method as a light, non-invasive, and interference- free respiratory monitor. Fiber optic sensors work by propagating light through optic fibers and detecting changes in light intensity, phase, or wavelength as a response to environmental or mechanical changes. Among the various kinds, plastic optical fibers (POFs) have attracted significant interest in biomedical sensing due to having superior mechanical flexibility, biocompatibility, cost-effectiveness, and wearability with wearable devices. In contrast to traditional silica-based fiber optics, which are brittle and tend to be easily broken, POFs constructed from polymethyl methacrylate (PMMA) or other similar polymers can bend, stretch, and deform up to a series of times before breaking— making them extremely well-suited for application in continuous monitoring processes where dynamic body movement is present.

Plastic optical fibers have specific applications in respiratory monitoring in that they can be sewn onto clothes, strapped across the chest or abdomen, or integrated into belts worn across the body. They can measure chest expansion and contraction, gradients of air flow temperature, or pressure change—both of which are linearly proportional to the respiratory cycles. As long as the chest or the abdominal wall changes with breathing, the fiber is stretched or curved and produces modulation of intensity in light transmitted. Signal conditioning circuits or computer algorithms condition modulations for re-generating waveforms of breathing. Others employ D-shaped POFs, side-polished fibers, or multi-point fiber bundles to provide improved sensitivity and selectivity.

POF-based systems have been used in a range of applications from hospital and diagnostic environments to gyms and home care settings. Because they are resistant to electromagnetic interference, they operate well under MRI and CT scan facilities where conventional electronic systems malfunction. Furthermore, their soft and non-invasive nature also makes them suitable for use in pediatrics, geriatrics, and sleep monitoring applications. The potential to incorporate POFs into smartwear, adhesive tapes, and IoT-based platforms positions them as a strong candidate for next-generation personalized health monitoring technologies.

Plastic fiber-type breathing sensors are also investigated for discrimination between normal and abnormal breathing patterns, apnea episode detection, and for respiratory therapy monitoring of breathing depth and rhythm. Recent research indicates their application in multimodal systems to combine respiratory sensing with thermal, heart rate, and posture sensing—to provide whole body physiological monitoring.

In brief, plastic optical fiber technology is an excellent alternative to expand respiratory monitoring since it is flexible, secure, and flexible. POF-based systems, along with signal processing techniques, wireless data communication, and smart analytics, are on the verge of giving rise to miniaturized, secure, and friendly respiratory monitoring technology. These technologies not only provide a touch to the monitoring as precise and convenient but also allow clinicians and patients to be pro-active for respiratory care in various environments.

LITERATURE SURVEY

[1] Respiration monitoring is critical to patient safety when anesthesia or sedation is being used. Conventional electronic sensors such as piezo belts, thermistors, and strain gauges are unsafe since they generate electromagnetic interference. These sensors degrade image quality, create artifacts, or even cause RF heating burns. Early solutions were to shield the electronics or create MRI-compatible versions, which were usually expensive or technologically underdeveloped. The shortcomings of such traditional systems prompted research on photonic substitutes, i.e., plastic optical fibers (POFs), being non-metallic and naturally resistant to electromagnetic fields. Yoo et al. surmounted this challenge by developing an MR-compatible respiratory sensor using polymethyl methacrylate (PMMA) POFs. The two-sensing system consisted of a nasal thermochromic sensor and an abdominal optical bending sensor. The nasal sensor sensed airflow temperature change as a function of change in light transmission due to pigment, and the abdominal sensor sensed torso expansion by measuring curvature- induced light attenuation in the fiber. These two non-electric channels delivered real-time simultaneous respiratory rate monitoring without halting MRI scanning. This modularity is simply integrated into existing patient prep routines without increased risk.

The benefit of this system is that it is passive. Having no electronic elements in the sensing field, it was free from chances of radiofrequency-induced heating or signal distortion in the MRI fields. The study was accurate performance compared to BIOPAC systems, with the added benefit of being completely safe for imaging procedures. This was a huge milestone in monitoring patients sedated for diagnostic scans. It also allowed physicians to continuously monitor vital signs without being required to disrupt the imaging run, thereby maximizing workflow efficiency and patient throughput. Yoo's work has since been copied by further studies in MRI-compatible biosensors, including fiber Bragg grating (FBG)-based and photonic crystal fiber designs integrating multimodal sensing in clinical environments. These more recent devices build on Yoo's contributions through the use of layers of functionality such as pressure, heart rate, or temperature sensing in one fiber network [10]. The ability to integrate sensing mechanisms into headbands, gowns, or masks is particularly beneficial in pediatric neuroimaging and MRI where movement needs to be minimized. In addition, this setup can easily be adapted to sense other physiological signals like heart rate and oxygenation by inserting layers of sensors

Future uses of this model may result in the creation of plug-and-play optical links for hospital use or the use of multiplexed fiber networks to monitor multiple patients simultaneously in intensive care units. The low cost, disposability, and versatility of PMMA fibers also suggest their use in outpatient monitoring and field diagnostic kits. These features complement growing trends for minimally invasive patient treatment and remote diagnosis. Moreover, interoperation with light-based wearable electronics can also introduce hybrid devices as an option, combining photonic and digital display to provide improved precision. In addition, the combination of this technology with wireless optical readouts would render tethered configurations obsolete. With real-time imaging and AI-based diagnosis becoming increasingly common, the inclusion of respiration-sensing within the imaging pipeline could make care delivery more streamlined.

In summary, the PMMA-based MR-compatible system shows how conventional photonics can be translated into critical care monitoring, closing the loop between safety, reliability, and clinical performance. It also emphasizes the potential of straightforward optical principles used considerately under biomedical restrictions an idea fundamental to the development of fiber optic medical sensors. The system has brought about new possibilities in safe, precise, and maintenance-free vital sign monitoring in delicate medical conditions.

[2] With medicine moving further away from the clinical setting and into homes and exercise stations, wearable technologies are essential. The challenge remains, however, to create wearable, precise, and washable respiratory sensors in a manner that is comfortable. Initial advances in wearable sensors utilized cumbersome electronics or inorganic wires embedded in garments, sacrificing both comfort and mobility. With the arrival of textile optical fibers, particularly through the application of POFs, researchers started investigating non- electronic systems with better sensitivity and higher wearability. Such fibers are mechanically compatible for use in textile weaving in addition to possessing good signal fidelity after frequent flexure and compression.

Krehel et al. built on this idea by encapsulating Geniomer- based POFs within elastic clothing. The fibers are sensitive to thoracic expansion with breathing through modulation of transmitted light intensity. A variety of fiber geometries were investigated—straight lines, meanders, and half-ovals—to enhance mechanical-to-optical coupling. The half-oval spiral geometry exhibited higher sensitivity and robustness and is suitable for respiration monitoring under dynamic conditions. Their new approach allowed the sensor not only to act as a breath rate detection tool, but also as a breathing type classifier—opening doors to diagnostic information from wearable textiles.

The system could distinguish between diaphragmatic, upper- costal, and mixed breathing types. This differentiation is important in the diagnosis of shallow breathing, anxiety- induced hyperventilation, and neuromuscular impairments. Signal conditioning and filtering in MATLAB allowed for accurate reconstruction of waveforms, with results closely matching those from reference spirometry devices. Their algorithms allowed breathing phases (inspiration and expiration) to be isolated with sufficient clarity to extract rate, amplitude, and variability, thus supporting richer data analytics.

One of the strongest aspects of the research is that it focuses on wearability and durability. The sensors functioned after several wash cycles and mechanical deformation, critical to consumer and clinician uptake. This places the technology on the cusp of smart garment use for everything from neonatal monitoring to geriatric monitoring and sports performance feedback. It also increased comfort and flexibility by incorporating soft fabric that made the fiber practically imperceptible to the wearer, helping to encourage compliance with long-term wear.

[3] Complementary studies on wearable platforms—such as Solunum Wear have shown that combining posture sensing and breathing monitoring enhances the diagnostic yield. Fabric with many sensing fibers is even capable of tracking sleeping position, essential for sleep apnea control. The Krehel system is scalable at low expense and much less so than rigid commercial sensors, which tend to need frequent recalibration. Their research has been cited as a blueprint for future multi-sensor e-textile design that also monitors heart rate, posture, and temperature.

The technology also makes possible applications in stress monitoring, where respiration rate and pattern can be used as surrogates for emotional states. As mental health consciousness grows, passive monitoring devices such as these integrated into regular clothes can potentially provide early warnings and facilitate therapeutic intervention. Geniomer's biocompatibility and elasticity also enable it to be combined with active heat- or humidity-sensitive materials to create next-generation adaptive clothing. Such garments can be self-adjusting tightness, insulation from heat, or even rigidity depending on the breathing activity detected.

The vision plan of this technology is to integrate Bluetooth or NFC modules to enable wireless data transmission and facilitate real-time cloud analysis. Such machine learning-based sensors would have the potential to make clothes AI-capable and responsive to pre-occluded respiratory distress signals. Krehel's research thus not only revolutionized wearable sensing but also reimagined possibilities for next-generation healthcare textiles. Their sensor platform thus embodies the confluence of comfort, function, and intellect in textile technology—a quantum leap of gigantic scale towards individualized health care.

Together, optical fibre fabric systems present an unseen means of incorporating health monitoring into everyday living. The transition from lab-based belts to smart fabrics is the path to non-invasive, real-time health monitoring—health as wearable. With advancements in the technology, the intersection of fabric formation, photonics, and bioinformatics will be the driver in creating the next wave of responsive, tailored garments for medicine and lifestyle.

This technology's vision model is to integrate NFC or Bluetooth modules to provide wireless data transmission and enable cloud analysis in real time. Machine learning-capable sensors like this can potentially make clothes AI-powered and responsive to pre-occluded respiratory distress signals. Krehel's work thus did not just revolutionize wearable sensing but also redefine future possibilities for next-generation health fabrics. Their sensor platform thus stands at the confluence of comfort, functionality, and intelligence in textile technology—a leap of colossal magnitude towards personalized health care.

Combined, optical fibre fabric systems provide an imperceptible means of incorporating health monitoring into everyday life. The transition from laboratory-based belts to smart fabrics is the path to non-invasive, real-time health monitoring—health as wearable. As the technology evolves, the intersection of fabric manufacture, photonics, and bioinformatics will be behind the creation of the next generation of responsive, tailored clothing for medicine and lifestyle.The sensor performed satisfactorily under physical states such as resting, walking, and running. Wavelet denoising and fast Fourier transform (FFT) were applied in a signal processing pipeline to demix breathing signals and motion artifact. Calibration trials yielded superior linearity ($R^2 = 0.9977$), signifying the reliability of the system.This technology answers the need for health tech that is compatible with motion. From rehabilitation at home to fitness apps, wearable sensors have to work in shapes, motion, and environments. Wang's D-shaped design does this without losing simplicity or cost. It's a crucial step towards democratizing health tracking for everyone, including rural or low-resource populations.

Outside of respiration, this sensor is able to be set up to detect other biomechanical signals. Curvature sensitivity can be calibrated to sensitivity to postural or even gait. The system can be wireless by microcontrollers to smartphones, which provide the function for real-time feedback, logging, and alarms.

Side-luminescent and photosensitive fiber synthesis [5] can now enable one to sense humidity, temperature, and breath together. Multimodal platforms in this way improve the utility of the sensor during fever, dehydration, or sensing early respiratory infection—especially for pandemics or management of chronic disease.

Future technology could involve the production of sensor arrays with different curvature thresholds to offer spatial respiratory mapping. These may identify asymmetrical respiration or identify thoracic injury at a localized level. The use of AI-enabled anomaly detection may identify nascent disease states such as COPD or fibrosis.

Wang's study is just one example of the move towards credible, intelligent, and user-centered health wearables. Its use with IoMT frameworks enables safe information sharing with healthcare professionals in an effort to minimize diagnosis delays and remote health care. As the wearable ecosystem continues to grow, curvature-based POF sensors will continue to be a stalwart of physiological monitoring solutions going forward.

[4] Respiration monitoring is a critical parameter in the measurement of an individual's health, particularly in clinical settings where detection of abnormal breathing patterns at an early point may be crucial. Respiration has been monitored conventionally using contact or non- contact sensing. Non-contact sensors in radar, infrared, and video-based systems are typically advanced and costly, restricting their use and availability in large-scale deployment and portable or space-limited applications. Contact sensors, especially flexible material-based and integrated electronic sensors, are cheaper and can be directly embedded inside clothing or integrated wear patches. Among them, fiber-optic sensors have demonstrated themselves as a promising choice because of low weight, no metal components, and strong resistance to electromagnetic interference

The authors in this work propose a novel plastic optical fiber (POF) sensor that is totally constructed from POFs for respiration sensing to offer a contact-type of respiration measurement without the restriction of traditional metallic or electronic sensors. The sensor device adopts an uncomplicated light intensity modulation method where the respiratory activity deflects the alignment between an input POF and a number of output POFs. The input fiber, which is joined to a 660 nm red light source LED, produces light partially interrupted or deflected with each up-and-down motion of the chest upon breathing. Three output fibers, which are connected to photodetectors, pick up the varying intensity of light and convert it to an electric signal as a representation of the pattern of breathing. The signal is conditioned by a compact, portable circuit supplied by a standard USB power supply and gathered through a DAQ interface to a computer.

Two healthy subjects, one male and one female, were tested in sitting and reclining positions. The sensor was attached to the apex of the chest using medical-grade adhesive tape. All subjects were subjected to a series of normal and deep (chest) breathing cycles. Calibration was achieved by comparing the signals with those acquired simultaneously from a commercially available respiration monitoring belt system. The output signals from both systems were compared on the basis of waveform shape, signal amplitude, and respiration rate. Under all conditions, the new POF sensor generated reproducible and discriminative normal vs. deep breathing signals. The waveforms on recording had clear periodic patterns which matched well with breathing cycles and thus demonstrated the responsiveness of the sensor to thoracic movement.

In particular, the POF sensor produced less noisy signals with reduced motion artifacts than the commercial belt in deep breathing or recumbent positions. This indicates that the conformability and weightlessness of the POF sensor diminish body movement interference or posture change interference. Besides that, in comparison of the values of respiration frequency measurement in both systems, the two were highly similar to each other with an extreme error rate not more than 4%. This strong correlation guarantees the plastic optical fiber sensor to achieve stable performance up to a standard comparable to other commercially applied ones.
This paper illustrates the viability of a low-cost, MRI-compatible, and simple-to-produce respiration monitoring system using plastic optical fibers. The use of 3D-printed parts and minimal optical alignments simplifies and lowers cost, making mass production feasible. Discrimination capability between various intensities and breathing patterns is also illustrated to have the potential to be used in respiratory therapy, sleep studies, or telemedicine. Its electromagnetic immunity makes it especially useful in applications such as magnetic resonance imaging, where conventional electronic sensors are impossible to apply. In general, this all-plastic fiber optical sensor is a major step toward cost-effective and non-invasive respiration monitoring technology

[5] Polymer Optical Fibers (POFs) have gained significant interest in recent years due to their potential properties such as high flexibility, low weight, ease of processing, and cost-effectiveness compared to traditional glass optical fibers. The paper provides a detailed overview of the history, properties, and potential application areas of POFs, with emphasis on their future potential in communication systems as well as sensing applications. POFs have primarily a polymeric core and cladding, typically made of polymethyl methacrylate (PMMA), and exhibit high numerical aperture and moderate rigidity, allowing them to find applications in short-distance communication as well as in embedded sensors.

The authors begin by grouping POFs based on the core material as well as on the refractive index profile. Some of the most common types are step-index POFs (SI-POFs), graded-index POFs (GI- POFs), and micro structured POFs (mPOFs). SI-POFs are simpler and are typically utilized for short-distance data transmission, while GI-POFs, having radial refractive index profile, provide superior bandwidth performance. mPOFs, however, have complex inner air- hole profiles, which allow for tailoring of optical and mechanical properties for target uses. The review also suggests that ongoing advances in polymer processing and fiber design have made major strides in POFs' attenuation, bandwidth, and environmental stability feasible.

The paper discusses the mechanical advantages of POFs, such as increased elastic limits and fracture resistance upon bending or stretching, and hence are ideal candidates for dynamic sensing applications. POFs are stronger than silica fibers and are best suited for medical, automotive, and wearable technology applications. Large core size also facilitates easy coupling with light sources and detectors, reducing system costs.

However, one of the biggest challenges remains the higher optical loss of POFs, particularly in the visible spectrum, but this is more and more being overcome by improvements in materials and processes.

Most of the paper is devoted to describing the use of POFs in sensing. Due to their strain sensitivity and temperature, humidity, and chemical changes sensitivity, temperature- based POF sensors are increasingly being engineered for structural health monitoring, biomechanics, and industrial safety. The simplest technique is intensity-based sensing, where optical power changes are caused by environmental changes, though more advanced methods like fiber Bragg grating (FBG) and interferometry are also being developed in polymer form. The article also includes a comparative account of silica fiber sensors and POF sensors with the note that the latter is more mechanically resilient and cheaper, but with reduced optical performance.

Finally, the review discusses new directions in the guise of optical communication on POFs in home networks (IEEE 802.3bv standard), automotive Ethernet, and integration of POFs into smart wear and medical equipment. The convenience of manipulation, adaptability, and safety (non- fracture properties) of POFs make them eminently suitable to embed in situations where conventional glass fibers would be inconvenient or risky. The conclusion of the paper summarizes lines for future research studies to be taken up, for example, additional reduction of transmission loss, designing novel polymer material with better optical and mechanical qualities, and additional commercial application for sensing and communication purposes

COMPARITIVE ANALYSIS

Aspect	[1]	[2]	[3]	[4]	[5]
Objective	Develop MR-compatible respiratory sensor using POF	Create wearable, textile-integrated respiratory monitoring system	Build low-cost, wearable system using D-shaped POF	Design a fully plastic, non-electrical sensor for respiration monitoring	Review of POF properties, classification, and sensing/communicatio n applications
Sensor Type	PMMA fiber for thermal and mechanical sensing	Geniomer-based pressure-sensitive POF	D-shaped POF with curvature-based detection	Input-output misalignment using light-blocking with POFs	SI-POF, GI-POF, mPOF — classified by refractive index and structure
Microcontroller/Interface	Not explicitly used (optical-only sensor output)	Amplification circuits + MATLAB signal processing	C8051F020 MCU, LED (645 nm), photodiode receiver	DAQ interface, PC waveform logging	Not application-specific; general suitability for optoelectronics and embedded systems
Detection Principle	Thermal and mechanical expansion alters light intensity	Pressure changes deform fiber and attenuate signal	Curvature-induced power loss	Thoracic movement alters alignment between input and output	Environmental changes (strain, temp, chemical) modulate intensity or wavelength

				fibers	
Target Parameters	Respiration rate	Respiration rate, breathing type	Respiratory activity under motion	Respiration waveform, frequency, intensity differences	Temperature, strain, pressure, humidity, chemical changes

FUTURE SCOPE

The future prospect for fiber-optic respiratory monitoring systems technology is immense in the healthcare technology sector. The most vital use for innovation is their integration with smart wearable textiles and Internet of Things (IoT) platforms to enable real-time remote health observation from the convenience of a patient's own home. This can be extremely useful to elderly patients, patients with chronic conditions, and long-term respiratory patients. Further, incorporation of machine learning techniques can also support the diagnostic capability of such devices by detecting aberrant respiratory patterns, estimating probable health complications, and facilitating patient-specific healthcare intervention. Extension to the application of fiber-optic sensors from monitoring the respiratory system, to multimode sensors able to monitor heart rate, temperature, and motion as well, there is thus also enormous potential for further applications of such fibers. Inside hospitals, they can be miniaturized to examine over one patient at a time with multiplexing technologies to make intensive care units more efficient. Additionally, with advances in low-power wireless communication and miniaturization technology, cloud-computing- and fully portable-based monitoring systems are possible. These would be especially convenient for application in remote or low- resource settings where top-of-the-line medical hardware is not available. In general, ongoing advancements in fiber-optic sensor technology form the foundation for developing the future of non- invasive medical monitoring and diagnostics.

CONCLUSION

This report emphasizes the critical advancements and growing interest in developing smart, non-invasive breathing monitoring sensors through optical fiber technology, notably Plastic Optical Fibers (POFs). These POF-based sensors possess relative benefits over conventional electronic sensors with immunity to electromagnetic interference, hence sitting very well to apply in Magnetic Resonance Imaging (MRI) environments and other electromagnetically noisy situations. Their flexibility along with their biocompatibility can be achieved through the capacity to produce biocompatible and flexible sensors.

Two primary types of fiber-optic respiratory sensors were found by the study: nasal cavity-mounted sensors using thermochromic pigment to sense temperature gradients in airflow and abdomen- mounted sensors using mechanical deformation sensing through modulation of light techniques. Both systems demonstrate the capability to record clean and precise breathing signals without compromising MRI image quality overcoming a major limitation of current monitoring systems.

Their direct comparison with clinically utilized equipment like the BIOPAC® system through efficient protocols also attests to their sensitivity and accuracy. Their MRI compatibility, non- invasive nature, and ability to work without electrical components in the sensing area point to a major breakthrough towards safe, efficient, and patient-friendly respiratory monitoring devices.

Furthermore, the optical method is also well suited to multiplexed systems where multiple different physiological parameters can be monitored simultaneously on a single optical network. Sensor designs oriented towards a wide range of different applications—from neonatal monitoring all the way through to surgery monitoring—demonstrates the flexibility of the technology
Even with such promising developments, there are challenges to be overcome. Long-term stability, environmental sensitivity (e.g., humidity and temperature), and mass field deployment need to be overcome. Wireless data transmission interfacing and small signal processing modules will also be important to use in practice.

Fiber-optic respiratory sensors effectively illustrate a vision of future solutions to real medical monitoring problems combining accuracy, safety, and flexibility in a way incompatible with traditional systems.

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