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RESEARCH ARTICLE

Development of a Novel Liquid Level Measuring and Monitoring Sensor Based on the Polymer Optical Fiber

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ABSTRACT

This paper outlines developing and applying a multi-point liquid level measuring and monitoring sensor by utilizing polymer optical fiber (POF). Traditional liquid-level sensors often face limitations of susceptibility to corrosion and electromagnetic interference. The proposed POF based sensor offers advantages, including immunity to electromagnetic interference, flexibility, durability, and multi-points measurement. Through advanced fabrication techniques and sensor design, this paper presents to create a reliable, cost-effective, and versatile solution for measuring and monitoring liquid levels for various industrial and environmental applications. The research in this paper involves the fabrication of the POF sensor, optimization of its performance characteristics, and demonstration of its effectiveness through experimental testing. The resulting sensor have the potential to revolutionize liquid-level monitoring systems, offering improved accuracy, longevity, and adaptability to diverse environments. This research developed a reliable, efficient, and cost-effective solution to simultaneously measure liquid levels at multiple points, leveraging the unique properties of POF for sensing applications.

Keywords: Optical fiber, Polymer optical fiber, POF sensors, Liquid-level sensors, EMI in PoF, FPG sensor design

1. Introduction & background

Polymer Optical Fiber (POF) is a type of optical fiber made from polymer (plastic) materials instead of traditional glass (silica). It transmits light signals through a core made of transparent polymer, usually PMMA (Polymethyl Methacrylate), and a cladding layer made from another polymer with a slightly lower refractive index. It is made from Core PMMA (Polymethyl Methacrylate) a high light-transmitting plastic, Cladding: Fluorinated polymer that keeps light confined inside the core by total internal reflection. Its Diameter: Much larger than glass fiber (typically 1 mm vs. 50–125 μm for glass fiber) [5]. Like glass fiber, it works on the principle of total internal reflection — light entering the core at a certain angle keeps reflecting within and travels long distances with minimal loss. But it has certain disadvantages like Higher signal loss (attenuation) than glass fiber so that it is suitable for short distances only (up to 100 m typically), temperature-sensitive polymers soften at high temperatures and limited bandwidth compared to silica fibers [5]. In our daily lives, we are connected to liquids. Water is abundantly used for every purpose. Besides water, fuel and different kinds of liquid are used. Among different liquids, a few types of liquid require special protocols to be stored safely. Further, the stored liquid could

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be used for different applications [5, 12]. The stored liquid requires monitoring to know the level of liquid. Different techniques are already used for level monitoring based on the mechanical and electrical systems. For many applications, neither mechanical nor electrical systems are suitable due to the precise level of monitoring and inherent safety.

Conventional liquid-level sensors employ various technologies such as ultrasonic, capacitive, and float-based sensors [5]. While, these sensors have been widely used, they often suffer from limitations that affect their performance and reliability. For example, float-based sensors are prone to mechanical failure and unsuitable for corrosive or abrasive environments. Capacitive sensors may experience drift due to environmental factors, and ultrasonic sensors may be affected by temperature variations and air bubbles in the liquid [12]. Moreover, many traditional sensors are susceptible to electromagnetic interference, which can lead to various results. Meanwhile, they are restricted to single point, which have deficiency of multi-point future.

In contrast, POF offer unique advantages that make them well-suited for sensing applications. POF are made of polymer materials, which offer flexibility, ease of handling, and immunity to electromagnetic interference [11, 19]. POF also exhibit low attenuation, allowing signals to travel over longer distances without significant loss. These characteristics make POFs ideal for use in harsh environments and for applications where traditional sensors may struggle to perform reliably [20, 21].

2. Literature survey

For mechanical and electrical systems, a number of techniques are used. The technique and instruments include Float or Buoy Systems, Pressure Transducers [1], Hydrostatic Level Sensors [2], Ultrasonic Sensors [3], Acoustic Doppler Profilers [4], Radar Level Sensors [5], Capacitance Level Sensors [6], Bubbler Level Sensors [7], Float Operated Mechanical Systems [8]. However, POF are flexible and durable — resistant to bending and vibration, Lightweight and cheaper than glass optical fibers, Easier to install — can be cut and connected easily, Safe, non-conductive, so no risk of electrical interference, visible light (red LED) compatible means simplifies alignment and testing [21]. The POF material has flexibility which can be used for the sensor fabrications. The sensor designed from POF will be simple and flexible structure. The simple and flexible structure of POF based sensor, will be measure and monitor liquid levels at a low cost. Further, the POF material has the property which is free from corrosion. Thus, these significant advantages of POF sensors have attracted attention for the last few decades [9–11]. The POF sensors can measure the water level based on a single point and multiple points. Numerous researchers wildly apply different techniques to utilize the POF material for water level sensing. The methods include the side polish of fiber [12], fiber brag gratings[13], and fiber twisting and bending structures [14]. M. Lomer et al. [15] used fiber polishing at the bend area to measure the water level. They used multiple points in the fiber by a u-shaped bend for the polish bend. Marques et al. [16, 17] measured the liquid level using FBG techniques. Their proposed fiber brag grating sensor technique used five different sensing points. Their experimental results indicate that the proposed FBG sensor design is highly sensitive when measuring the liquid level. In a broad sense, the liquid height changes even at the bottom level. Measurement of the height of a liquid could not give sufficient information about the quantity of energy stored in a liquid, such as optional energy in the case of a hydropower reservoir. For the hydropower reservoir to measure the water level in sloped ground conditions, the water height at initial point (tail point) and final point (penstock). In addition to above, POF are also used in data Communication (Short Distance), such as Home networks (FTTH). Office LANs, Industrial Ethernet systems (e.g., PROFIBUS, EtherCAT, vehicle communication networks (e.g., infotainment systems in cars), Consumer Electronics like Digital audio links (TOSLINK) for connecting DVD players, sound systems, and TVs, Illumination & Decorative Lighting such as star ceilings, displays, and signage lighting, Museum and architectural illumination, industrial and medical equipment such as sensors for strain, temperature, or pressure, Short-range data transmission in factories, endoscopy and imaging tools [19–21].

3. Methodology

The above study of various researchers attracted to fabricate the sensor from POF to utilize for liquid level measuring and monitoring applications. The best of our knowledge, the POF based liquid level sensors measure liquid level by the intensity variation. To enhance the importance of the POF based liquid level sensors, the present study designs the multi-point liquid level sensor. The proposed idea works to identify the liquid level at various points based on the single control system. The sensor's basic principle is to

couple light from one fiber to another fiber through side coupling. The primary fiber has been directly connected with the power light source LED for the input light source. Further, to activate the sensor, the variation in liquid level has been sensed based on the variation in coupled light in the secondary fiber. The variation in light coupling is due to the change in the reflected index between air and water. The light from one fiber to another has been coupled by tightly twisting the secondary fiber with the primary fiber. Further, twisted fiber has been bent based on the system requirement. The number of bents have been applied for multi-points liquid level measurement. For every bent, the secondary fiber has been independently twisted with the primary fiber.

Fig. 1 shows the overall process chart of the present project. This focuses on introducing a novel sensor for liquid level measuring and monitoring. The sensor design initiated from the single sensor to multiple sensors. The sensor is based on a single input and multiple outputs.

Liquid level measuring and monitoring are critical in various industries, including chemical processing, petroleum, wastewater treatment, and environmental monitoring. Accurate and reliable measurement of liquid level is essential for ensuring operational efficiency, safety, and environmental compliance.

3.1. Project description

This article is centered on developing a multi-point liquid level measurement and monitoring system through polymer fiber sensors that aimed to leverage the technological advancements in POF sensing to offer a novel solution for accurate and efficient liquid level monitoring across a range of applications. The project fabricated the sensor using PMMA. This fiber known as acrylic, is a transparent thermoplastic with many applications. The physical property of PMMA fiber makes it valuable for liquid-level sensor fabrication. The properties of fiber transparency, flexibility, chemical resistance, weather resistance, and high strength of fiber made it the best choice to fabricate the sensor for liquid level detection and monitoring. Our project is applicable to water level measurements in agricultural fields, urban water systems, industrial processes, and natural water bodies. Further, for fuel level monitoring, the project is applicable for various fuel storage purposes, from containers for fuel transportation to fuel storage. Where, for chemical, our proposed poject will be applicable to use for non-reactive chemical level measuring. Fig. 2 gives an overview of the required materials and equipment for the sensor fabrication and utilizes the sensor for liquid level measurement.

3.2. Objectives

Our research aimed to fabricate the multi-point sensor to utilize liquid level measuring and monitoring applications. The liquid level measuring and monitoring is a challenging task due to safety and reliability concerns. To consider safety and reliability issues, we have designed the sensor from POF based on the twisted structure [18]. We have worked that sensor for other applications such as humidity, robot moments, and displacement [19–21]. At present we focused to liquid level as well as imposing to develop multi-point detections. In this project, we had objectives to utilize our designed sensor for the proposed purpose. To efficiently use a sensor, we had the objectives such as sensor basic design, sensor multi-point design, chemical coat to avoid wettability, environmental monitoring and management to improve the significance of our sensor.

3.3. Key scientific problems solved

Developing a multi-point liquid level measuring and monitoring system using POF sensors involves tackling several key scientific and technical challenges. Addressing these problems ensured the system's accuracy, reliability, and applicability in real-world scenarios.

3.4. Research approach

Designing a multi-point liquid level measuring and monitoring system using POF sensors required a lot of effort to achieve the task. The project aimed to develop a highly sensitive, accurate, and durable system capable of real-time monitoring of liquid levels at multiple points. We have achieved the basic concept and idea above research approaches for multi-point sensor design. Fig. 3 gives an overview about the research approach.

4. Results and discussion

4.1. Sensor fabrication and operation principles

For this project, we planned to fabricate the sensor using POF. As our study understood that the POF is a cylindrical waveguide medium, which is transparent and flexible from a material point of view. The POF deliver/guide light for long distances with low losses. The basic structure of the fiber consists on the core and cladding.

To design the sensor's basic structure, the fiber needs to twist and bend to make the sensor probe. Fig. 4(b) presents the basic structure of the sensor.

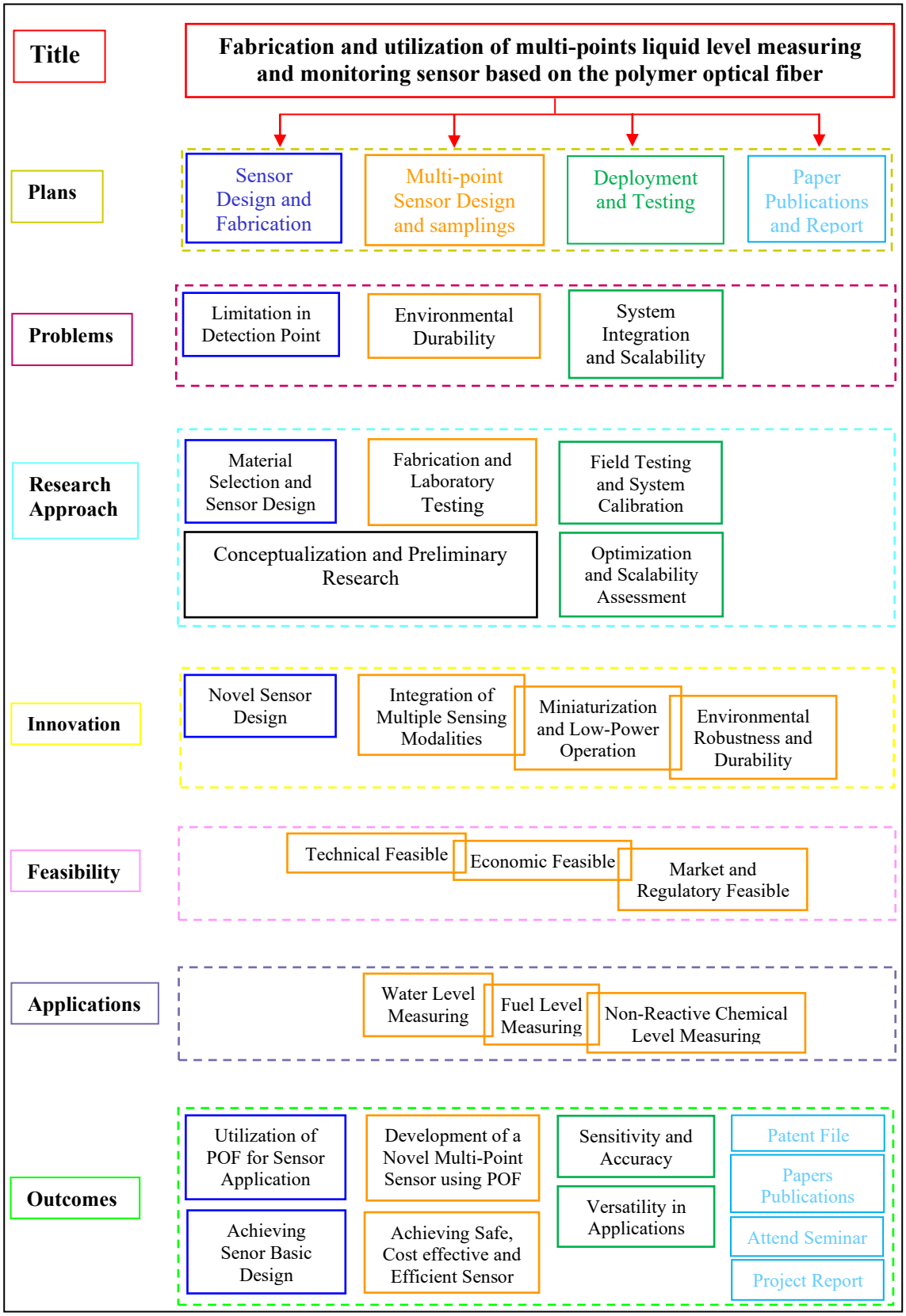

Fig. 1. Overview of the design.



Fig. 2. Required material and equipments (a) Polymer fiber, (b) Light LED (Mid Power Fiber Couple), (c) LED driver, (d) Silicon fiber power head, (e) Power and energy meter, (f) Agarose gel, (g) Water channel, (h) Reading machine.

Further, for multi-point liquid level measuring, the secondary fiber will be twist with the primary fiber at different positions to make a sensor series. Fig. 4(c) gives the overview of the sensor design with multi-point sections. The liquid level sensor measures the level based on the change in the R.I. The air is the reference R.I (i.e. 1), where the increased in water level leads to a change the R.I. To observe the influence of change in R.I on the light coupling from one fiber to another fiber, the two fibers were twisted with each other. From two fiber twisting, one is light input fiber, and the second is light output fiber. The light input fiber caries light from LED source, where the output fiber couples light from the primary fiber. The change in R.I due to medium change from air to water varies the amount of light coupling. The variation of light coupling is measured through a power meter, which was connected to the light output fiber. Fig. 2(c) shows the extended multi-points sensor up to n^{th} sensor. Which expected that multiple number of sensor could be fabricated in series.

4.2. Sensor integration into experimental Setup

Present project designed the multi-point liquid level measuring and monitoring sensor. The sensor is designed from the POF, producing output measuring readings based on the power coupling from one fiber to another. The variation of light coupling depends upon the change in the R.I. To get results through proposed sensor of project study, the sensor has been integrated into the different ground levels from even

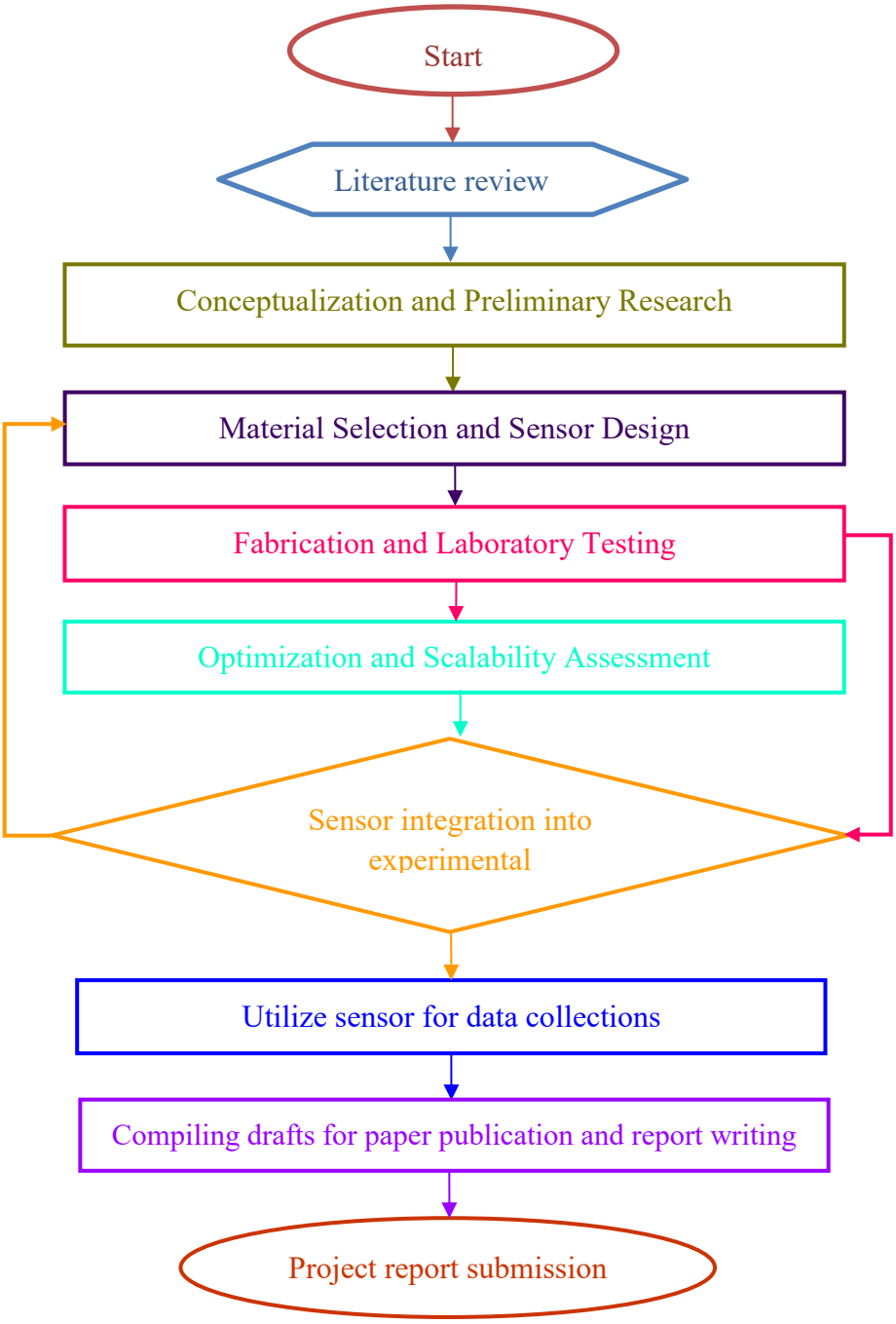

Fig. 3. Research flow chart.

to uneven ground level. Fig. 5 gives an overview of sensor integration in experimental setup at even and uneven ground levels. As we know at uneven base situation, the liquid level will change, and it will be a challenging task to get an accurate liquid level. The present study focused on getting successful results. The proposed liquid level measuring and monitoring project aimed to integrate the multiple sensors in series, especially for uneven ground conditions. The sensor structure contains the two fibers twisting with each other, and then the twisted fibers are winded on the supporting tube to generate the sensor probe. Both sensors were integrated into the open cubic water tank with even and uneven ground conditions, respectively. Both sensors are simultaneously active for even ground conditions as liquid level changes. While, in case of uneven ground level, both sensors are active respectively.

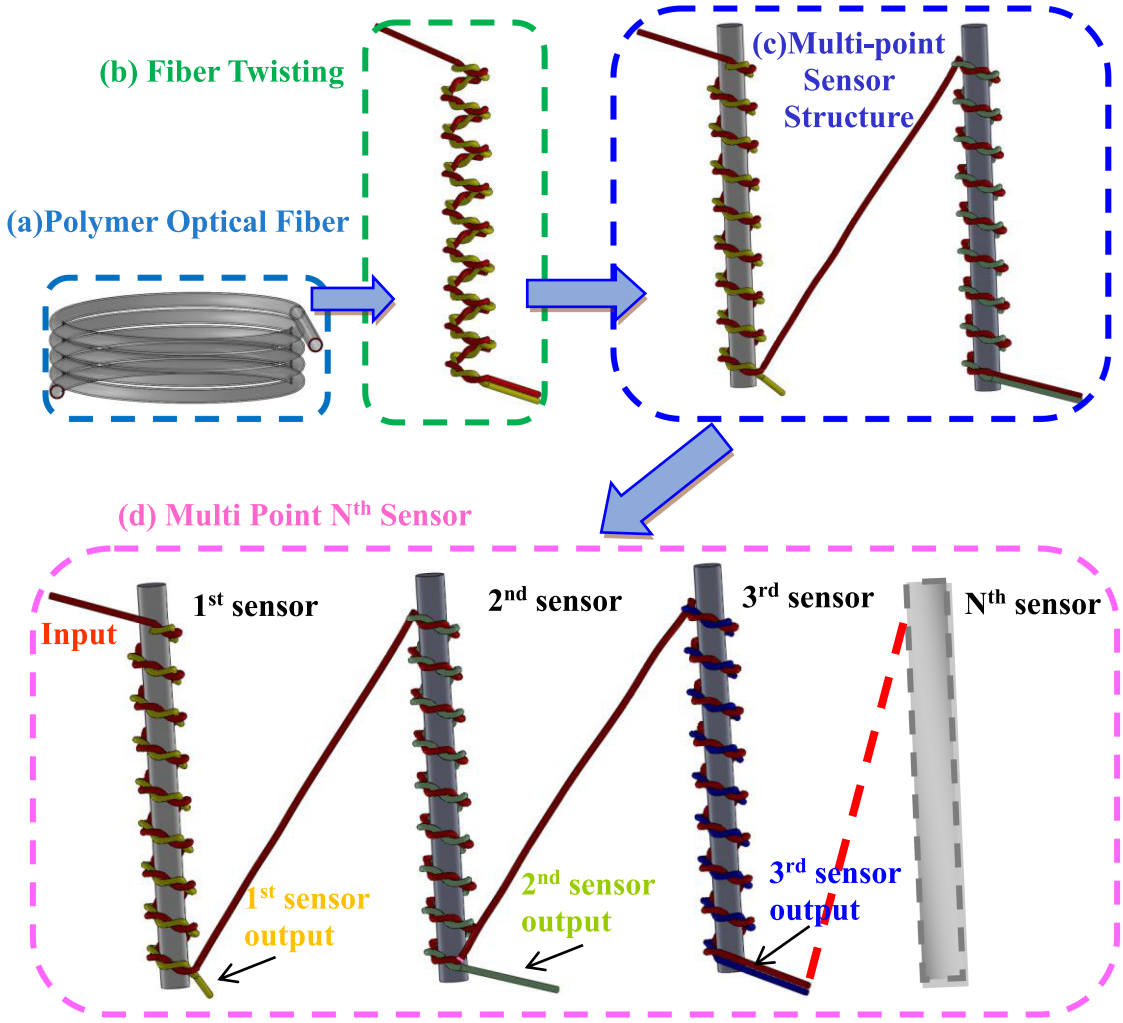

Fig. 4. Multi-point liquid level sensor fabrication.

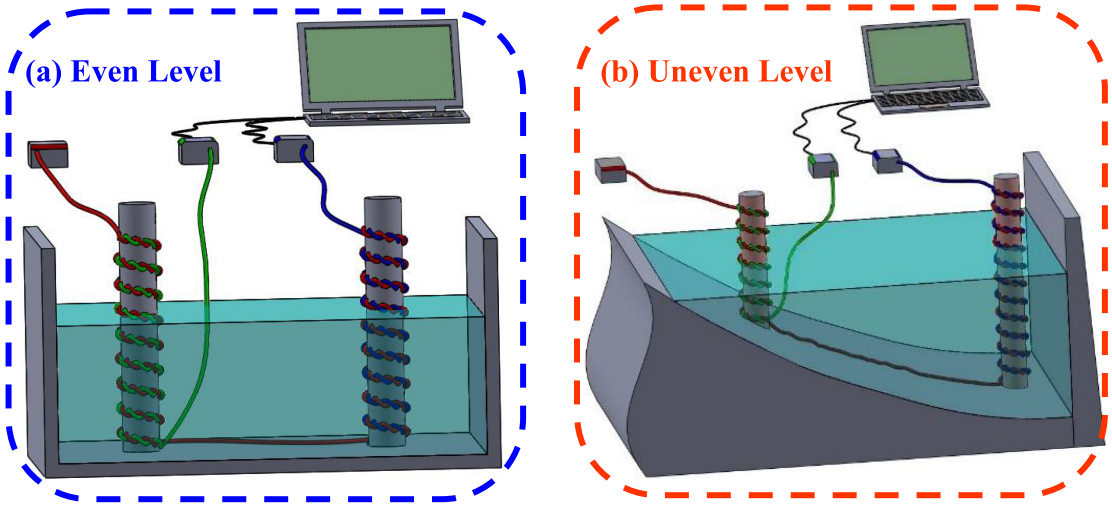

Fig. 5. Multi-point sensor integration at even and uneven ground level applications.

Table 1. Annual research plan.

Research Activities		Year 2025 (from January to December)											
		1	2	3	4	5	6	7	8	9	10	11	12
Sensor Design and Fabrication	Conduct a recent literature review												
	Fabricating and optimizing the sensor design												
	Fabricating and optimizing the side-illuminated method												
	Develop control algorithms for the activation sequence and frequency of LEDs												
	Fabricate a prototype of a sensor												
Multi-point Sensor Design and samplings	Multi-point sensor fabrication												
	Solving challenges of multi-point design												
	Develop a data acquisition system												
	Characterization												
	Conduct samplings												
Deployment and Testing	Integrate the sensor into the experimental setup												
	Integrate the sensor into the experimental setup												
	Conducting results												
	Characterization												
	Data collection												
Paper Publications and Report Writing	Compiling and manuscript												
	Project report writing												
	Project summarizing												

4.3. Annual research plan and expected results

4.3.1. Annual research plan

The primary goal of this proposal project's annual research plan is to develop, optimize, and validate a novel multi-point liquid level sensor. The sensor aims to accurately measure liquid levels at multiple points within a container or system, catering to various industrial, environmental, and consumer applications. The research plan outlines a systematic approach to sensor design, development, testing, and validation over the course of one year. The following steps are in consideration: Further, Table 1 gives the time frame of a research plan.

- Sensor Design and Fabrication:
- Multi-point Sensor Design:
- Deployment and Testing:
- Paper Publications and Report Writing

4.3.2. Expected outcomes

The project "Fabrication and utilization of multi-points liquid level measuring and monitoring sensor based on the POF" aimed to develop an innovative and efficient system for measuring and monitoring liquid levels in various applications. The focus of project is to create a system that is lightweight, flexible, and potentially more resistant to harsh chemicals and environments than traditional glass optical fibers. The expected outcomes of this project include:

- ❖ Development of a Novel Sensor:
- ❖ Enhanced Sensitivity and Accuracy:
- ❖ Cost-effectiveness and Scalability:
- ❖ Versatility in Applications:
- ❖ Contribution to Research and Innovation:

5. Conclusion

The research project titled "Fabrication and Utilization of Multi-Point Liquid Level Measuring and Monitoring Sensor Based on Polymer Optical Fiber (POF)" is designed to develop an innovative, reliable, and efficient optical sensing system for the precise measurement and continuous monitoring of liquid levels across diverse industrial and environmental applications. The core objective of this project is to design and fabricate a lightweight, flexible, and chemically resilient sensor system utilizing polymer

optical fibers, which offer distinct advantages over traditional glass optical fibers in terms of mechanical flexibility, ease of handling, and resistance to corrosion or degradation in harsh chemical environments.

The envisioned system seeks to leverage the inherent optical properties of POFs to enable multi-point detection, providing real-time and spatially distributed measurements of liquid levels with enhanced sensitivity, high accuracy, and improved signal stability. In addition, the proposed design aims to ensure cost-effectiveness and scalability, making it suitable for both industrial-scale and laboratory-scale implementations. The sensor's adaptability would allow it to be employed in a wide range of applications, including chemical processing, water resource management, biomedical systems, and environmental monitoring.

The successful execution of this project is expected to make a significant contribution to the fields of sensor technology, materials science, and photonic engineering by expanding the understanding of polymer optical fiber behavior in sensing environments. It may also stimulate further research and innovation in optical sensing methodologies, particularly in the development of next-generation, flexible, and smart monitoring systems that integrate optical fiber technology with modern data acquisition and control systems.

Overall, the completion of this project would represent a notable advancement in liquid level sensing technology, delivering a robust, accurate, and versatile sensing platform. Such a system could be widely adopted across multiple industrial sectors, marking an important step toward the broader application of polymer-based photonic sensors in modern engineering and environmental monitoring systems.

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

Author contribution

- **Altaf Hussain Bouk:** Conceptualization, methodology, and overall supervision of the research. Responsible for the writing of the manuscript and coordination among authors.
- **Abdul Quddus Bhutto:** Contributed to the experimental design and data analysis. Assisted in writing sections of the manuscript.
- **Mushtaque Ahmed Korai:** Involved in the fabrication of the polymer optical fiber sensor and optimization of performance characteristics. Provided critical revisions of the manuscript.
- **Nusrtullah Khan:** Conducted experimental testing and validation of the sensor's effectiveness. Assisted in drafting and editing the manuscript.
- **Abdul Ghaffar Abro:** Provided insights into the practical applications of the sensor in industrial settings. Contributed to the literature review and manuscript revisions.

Data availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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