Enhanced sensing of liquid levels: multipoint detection using twisted polymer optical fiber in cylindrical configurations

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ABSTRACT

Recent interest in water level detection is driven by the need for accurate monitoring in sectors such as agriculture, flood management, and environmental conservation. The measuring of liquid levels and solution concentrations is critical in a variety of industrial sectors. This research is to design, implement, and test the use of plastic optical fiber (POF) as an optical sensor for sensing multi-point liquid levels and densities. The developed device includes a multi-point liquid level sensor that uses refractive index modification of macro bend POFs selectively twisted around a cylindrical column. When the POFs were submerged in various mediums such as pure water, seawater, saltwater, and cooking oil, a set of U-shaped detecting heads was designed to detect changes in liquid levels. The experimental setup included an 850 nm optical light source and a power meter to measure the output power. A comparison of the performance of straight, bent, and twisted POF forms revealed that the twisted and bent POF topologies attained a sensitivity of 30%, exceeding bending-only 21% and twisting-only 12% configurations. In summary, changes in liquid levels resulted in an increase in output power for all liquid media, highlighting the potential of POF as a reliable sensor for sensing liquid levels.

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1. INTRODUCTION

Fiber optic technology is the primary mode of data transmission in the telecommunications industry, utilizing a simple process of converting electrical signals into light, transmitting them via optical fibers to a distant receiver, and then converting them back into their original electrical form. The capacity to transfer signals across long distances without requiring amplification is a significant advantage. It also alleviates concerns about interference from surrounding electrical fields. Beyond its predominant role in communication, fiber optics find application as sensors to gauge an array of parameters such as humidity, temperature, concentration, and water levels.

Over the past few decades, the advancement of fiber optic sensor (FOS) technology has led to the creation of sensors for temperature, humidity, and strain. These FOS have exhibited heightened capabilities, enabling them to supplant conventional sensors in a wide spectrum of applications. These applications encompass measurements related to vibration, acoustics, magnetic and electric fields, rotation, acceleration, pressure, temperature, linear and angular position, strain, humidity, viscosity, and chemical properties [1]. Notably, due to their dielectric qualities, these sensors can withstand extremely high voltages, high temperatures, and harsh environmental conditions.

High-performance sensor technology, defined by features such as elevated accuracy, reasonable cost, compact dimensions, durability, and operational ease, is critical for an effective, and trustworthy monitoring system. These characteristics are completely met by FOS technology. Optical fibers serve two functions in this technology, acting as intrinsic sensors, which is the sensing element or to convey signals from remote sensors to electronic devices for subsequent signal processing in extrinsic sensors. This dual capability highlights FOS technology's versatility and adaptability, firmly positioning it as a crucial component inside the modern sensor technology landscape.

Liquid level measurement plays a pivotal role in ecological and engineering research, particularly when dealing with the detection of easily conductive and flammable substances. Recent interest in water level detection is driven by the need for accurate monitoring in various sectors like agriculture, flood management, and environmental conservation [2]-[5]. Reliable water level sensors help manage resources, prevent disasters, and ensure efficient operations. The fundamental technology can be applied in smart irrigation systems, dam monitoring, and early flood warning systems, providing critical data to protect assets and the environment. Optical fiber-based liquid level sensors have gained significant attention and adoption in this domain due to their exceptional attributes, including resistance to electromagnetic interference, compact dimensions, low weight, robustness in harsh environment, and high measurement precision [6]-[13]. Various iterations of optical fiber liquid level sensors, such as those built on fiber Bragg gratings (FBG), long-period fiber gratings (LPFG), and fiber Fabry Perot interferometric (FPI) sensing, have been extensively developed and deployed. It is essential to note that the manufacturing of these sensors involves intricate and costly techniques, such as photoengraving, cutting, and bonding. For example, the production of fiber FPI sensors necessitates the delicate processing of micro-membranes at the fiber ends, involving tasks like polishing and film coating, which are notably complex.

A significant milestone in FOS technology occurred with the introduction of plastic of fiber (POF) which offers a reliable and cost-effective solution. POF sensors are sensitive, lightweight, and resistant to electromagnetic interference, making them ideal for detecting water levels in challenging environments [14]-[16]. In 1966, the first POF was introduced, using polymethyl methacrylate (PMMA) as its primary raw material, paving the way for subsequent innovations [17]. POFs are categorized based on their refractive index (RI) distribution, which can be either step index (SI) or graded index (GI), and their mode of propagation, which can be single-mode or multi-mode. SI multi-mode POFs are commonly employed in commercial applications due to their cost-effectiveness and ease of fabrication. However, they are associated with higher loss and multi-mode dispersion, limiting their transmission distances. In contrast, GI multi-mode POFs, characterized by a gradual RI reduction from core to cladding, mitigate intermode dispersion, enhance POF bandwidth, and extend transmission distances. The flexibility of optical fibers allows for the customization of POFs to meet a wide array of application requirements.

Currently, the prevailing technology for liquid level sensing in POF systems primarily relies on intensity or wavelength modulation. The estimation of liquid levels hinges on variations in optical loss resulting from changes in coupling conditions, absorption characteristics, and the presence of evanescent fields within the POF, particularly with a focus on intensity modulation. In optical fibers, the primary mode of light transmission is total internal reflection (TIR). According to Maxwell's equations, materials with low RI coatings retain residual energy in the form of an electromagnetic wave (EW) called an evanescent wave, which rapidly diminishes. In low RI media, this evanescent wave undergoes exponential decay upon traversing the reflective interface [18]. A comprehensive understanding of these principles forms the foundation for accurate liquid level measurements in POF systems, underscoring the pivotal role of FOS technology in contemporary sensor applications.

Conventional liquid level sensors available in the market predominantly rely on mechanical, ultrasonic, and electrical techniques [19]-[23]. These sensors often exhibit limitations, including being confined to point measurements, susceptibility to interference, large dimensions, or unsuitability for applications involving conductive liquids or potentially explosive environments. Recent developments have witnessed a surge of interest in technology based on macro-bending coupling of optical fibers for liquid level sensing. This approach offers advantages in terms of simplicity in construction, a wide measurement range, and impressive resolution [24]-[29]. Researchers have introduced liquid level sensors characterized by correlation and spiral structures, providing a measurement range of at least 0.9 meters and a resolution exceeding 10 millimeters. However, these sensors encounter challenges due to stringent processing requirements and low signal-to-noise ratio (SNR), which affect their measurement range and resolution [30]. A fiber optic bending sensor was introduced for water level monitoring, offering a measurement range exceeding 10 meters. Nonetheless, the associated processing techniques necessitate relatively high standards, resulting in substantial construction costs for the testing system [31]. Additionally, a liquid level detection method based on an optical fiber twisted macro-bend coupling system was proposed, but further research is essential to address aspects such as linear behavior and thermal effects [32], [33].

In this study, we embark on the endeavor of designing an experimental setup tailored for multipoint liquid level detection using bent and twisted POFs. The research aims to analyze the impact of bent and twisted POF configurations on multi-level liquid detection. Three distinct experimental setups were set. POFs with varied lengths ranging from 30 cm to 130 cm and diverse shapes were used in each experiment. As the principal light source, an optical light source with a wavelength of 850 nm was used. An optical power meter was also used to measure the output power. The experiment included the use of four different liquid mediums namely distilled water, seawater, salt water, and cooking oil. The major criteria under consideration were the liquid level and liquid density, as determined by changes in output power.

2. METHOD

In the first experimental setup, four single-point sensors with different POF formations were used to observe their performance. For the second experiment, the setup has single and twisted POFs that are twined and bent around a cylinder structure with a screw pitch of 4 cm. These POF form five U-shaped bends acting as sensing heads. The curvature radius of the macro bend section is 3.5 cm. In the third experiment, another setup is implemented where POFs, both single and twisted are placed in a straight line on the red cardboard. To enable comparison between experiments, POF sensors were placed in different containers. When the environment around the sensor head changes from air to liquid, the sensing point gets direct contact with the liquid. Hence, modulates the transmitted light energy based on the refractive index of the liquid. As a result, the light intensity at the sensing point varies with changes in the liquid medium.

It is imperative to remove the cladding of the POF to instigate fiber sensitivity for RI analysis. Ethanol is commonly utilized to strip a portion of the fiber plastic coating, rendering it more sensitive and augmenting the power of the evanescent wave within the POF cladding. However, the pursuit of chemical etching methods was discontinued due to the potential risk of damaging the fibers through bending and twisting. Consequently, this project opted for an alternative approach, employing sandpaper to achieve the desired effect. The POF was segmented into three distinct lengths which are 30 cm for single-point analysis, 110 cm and 130 cm for multipoint analysis utilizing a precision cutter. The process involved the meticulous removal of the fiber's outer protective layer, exposing the POF core, and subsequent tapering to achieve the desired diameter of 0.95 mm. The POF diameter was accurately measured using a digital micrometer.

Four distinct liquid compositions were meticulously prepared for this study, comprising of distilled water, salt water, seawater, and cooking oil. Each liquid variant possesses unique characteristics that can be accurately quantified employing a refractometer, an instrumental tool for assessing refractive indices. Table 1 provides a detailed record of refractometer readings, denoting the RI determined for the specified liquids.

Table 1. Refractive index for different medium

Liquid medium	Refractive index
Distilled water	1.3323
Saltwater	1.3399
Seawater	1.3374
Cooking oil	1.4647

2.1. Experimental setup

This research focuses on three separate experimental configurations. Experiment 1 with a single-point POF whereas experiments 2 and 3 with multi-point POF as shown in Figure 1. Figure 1(a) shows a cylindrical structure whereas, Figure 1(b) depicted a straight line with U bending for the POF.

(a) (b)

Figure 1. Multipoint POF; (a) cylindrical structure and (b) straight line

An optical light source with a wavelength of 850 nm was used in all experimental setups. This wavelength was chosen because of its established usefulness for POF applications. An optical power meter (RY-3200A) was used to measure optical output power. This power meter is specifically intended to measure optical signal power accurately, providing precise readings of the power output from the POF sensor. The POF, the light source, and the output power meter were all connected via a physical medium attachment (PMA) 650 connector. This connector must be carefully fitted and securely positioned in order to optimize performance and provide accurate results.

3. RESULTS AND DISCUSSION

The output obtained is the observation of single points and multiple points under several straight, twisted, bent, and twisted formations. All of these configurations have been compared for several liquid mediums including sea water, distilled water, salt water, and oil. The results from single point POF and multi point POF are observed and tabulated in the table and graph.

3.1. Single point in different formation

The performance of single point POF was evaluated using four different fiber formations namely single straight (SS), twisted straight (TS), single bent (SB), and twisted bent (TB) POF. The investigation used various liquid solutions including distiller water, seawater, saltwater, and oil to determine the impact of these various form on POF sensor output power. In this experiment, a 30 cm long POF was used, with a specific uncoated portion specified as the sensing point for liquid detection. The experimental data, which are recorded and summarized in Table 2, provide a complete output power in dBm differentiating measurements for air and liquid medium during the initial experiment.

Table 2. Output power in dBm for air and liquid medium at various configurations

	Distilled water (dBm)	Sea water (dBm)	Salt water (dBm)	Oil (dBm)
SS	1.03	1.34	1.55	2.41
TS	1.14	1.43	1.61	2.53
SB	1.21	1.41	1.62	2.62
TB	1.31	1.5	1.68	2.71

Based on the data, a graphical representation was created to evaluate the performance of the POF sensor across various fiber forms. This graphical analysis aided in the discovery of formations with high sensitivity, revealing optimal configurations. The graph specifically revealed that the twisted bend POF formation had greater sensitivity as compared to other configurations, confirming its enhanced ability to detect changes in liquid level and density. Furthermore, among the liquid mediums tested, cooking oil had the highest sensitivity, demonstrating the POF sensor ability to detect and measure liquids with high refractive indices. The larger the liquid refractive index the more significant the contrast with the air and in turn the more sensitive the mode coupling is to the liquid or air interface, which finally leads to a higher sensitivity to liquid level monitoring.

Figure 2 depicts the POF sensor performance across several forms in detail. Notably, oil distinguished itself significantly from water and saltwater among the four mediums studied. The investigation found that twisted and bending structures produced the maximum gain difference of 2.71 dB, exceeding the reference value of 2.41 dB and indicating a 30% increase in sensitivity. This was followed by only 21% bending and 12% twisting.

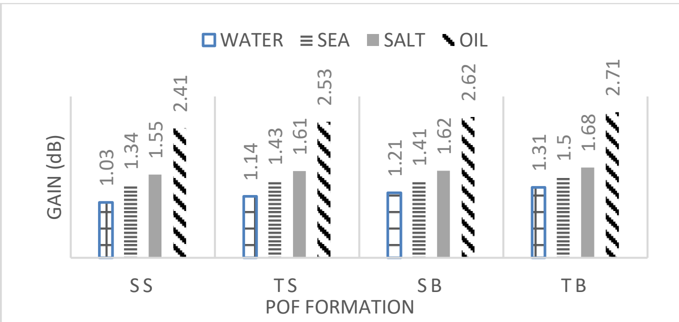
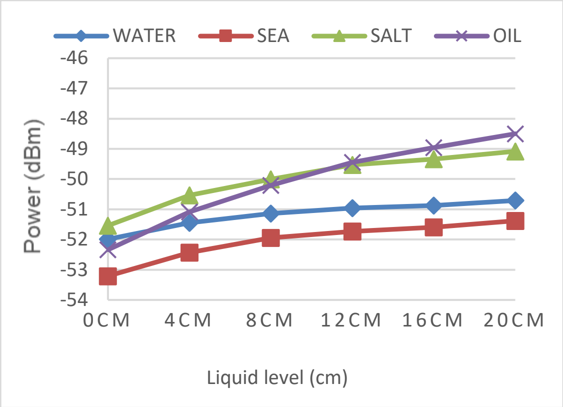


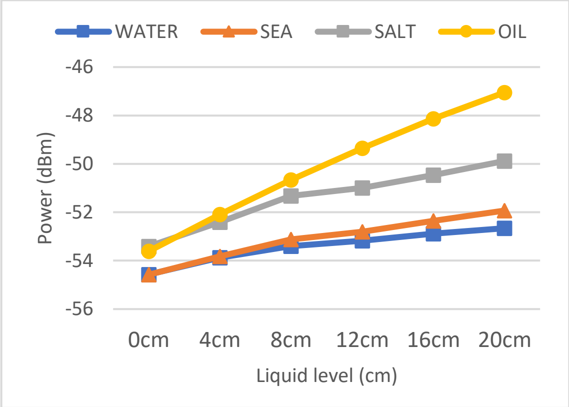
Figure 2. Comparison of different formation

3.2. Multipoint sensor in cylindrical structure

To develop a multipoint sensor within a cylindrical framework, two experimental setups were implemented, each utilizing a single straight and twisted POF. The recorded and collated results include extensive data on output power measured in dBm, obtained across a range of liquid levels and liquid compositions. This dataset was then graphically presented. Figures 3(a) and (b) depicted the dBm output power for multipoint SB and multipoint TB POF respectively. Clearly, an increase in liquid level corresponds directly to an increase in output power, highlighting an obvious and direct relationship between liquid level and sensor output power. Furthermore, different liquid media exhibit various gains, indicating a nuanced sensor response contingent upon the specific liquid medium employed.



(a)



(b)

Figure 3. Output power for multipoint; (a) SB and (b) TB

3.3. Comparison multipoint plastic optical fiber cylindrical structure

Figure 4 shows a graph that compares the performance of SB and TB POF. Because of their significant differences in gain output power, the comparison focuses primarily on two separate liquid mediums, distilled water and oil. The graphical representation clearly shows that the TB POF configuration has more sensitivity than the SB POF, as evidenced by the gain output power values for both distilled water and oil.

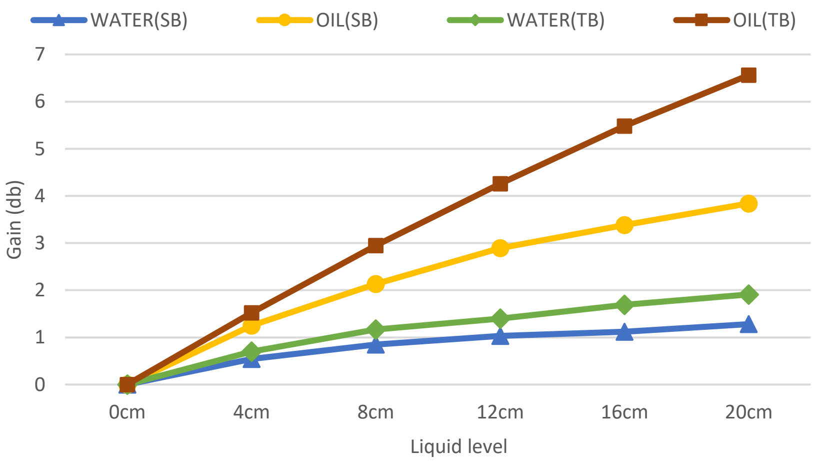
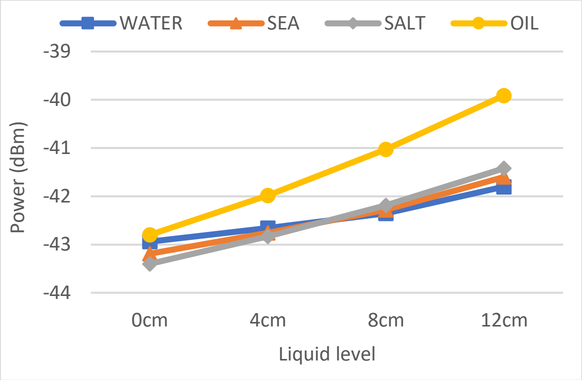


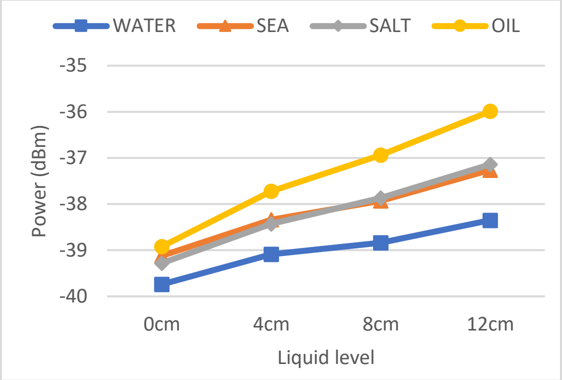
Figure 4. Comparison multipoint SB and TB POF in cylindrical structure for water and oil

3.4. Multipoint sensor in straight structure

To create a multipoint sensor arrangement in a linear shape, two experimental configurations were used, each utilizing a SS and TS POF. The data were painstakingly documented and summarized, including exact measurements of output power in dBm corresponding to various liquid levels and liquid compositions. This entire dataset was then displayed in Figure 5. Figures 5(a) and (b) vividly depict the output power for the multipoint SS and multipoint TS POF respectively. The graphical analysis clearly shows a constant connection, illustrating that an increase in liquid level corresponds proportionally to an increase in output power, demonstrating a direct relationship between liquid level and sensor output power.



(a)



(b)

Figure 5. Output power for multipoint; (a) SS and (b) TS POF

3.5. Comparison multipoint twisted plastic optical fiber in straight and bending structure

Figure 6 depicts a graph that compares straight and bending configurations of multipoint twisted POF. The primary focus of this comparison is on two distinct liquid mediums with significant sensitivity, distilled water and oil, which differ significantly in gain output power. The graphical representation clearly shows that the TB POF arrangement has higher sensitivity for both distilled water and oil than the TS configuration, as indicated by the gain output power differential.

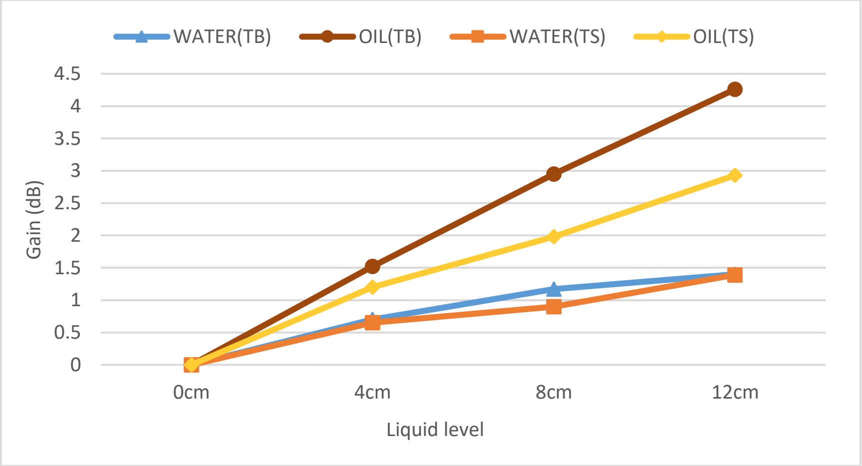


Figure 6. Comparison multipoint twisted POF in straight and bending structure

4. CONCLUSION

In conclusion, the objective of this project, which is to design and implement a simple, low-cost optical sensor based on tapered and macro bent twisted POF for liquid level and density detection, was successfully achieved. The performance of the sensor was evaluated using four different liquid mediums with different concentrations. The experimental results manage to show a consistent trend. As the concentration of the liquid medium increases, corresponding to a higher RI, the output power also increases. This observation is consistent with the basic principle that a sensing point in direct contact with a liquid modulates the transmitted light energy based on the RI of the liquid. As a result, the light intensity at the sensing point varies with changes in the liquid medium. Throughout the experiments, the different formation of POF has a significant impact on the sensor's performance. The analysis shows that the multipoint twisted and bending POF can produce higher sensitivity than single point POF without bending and twisted. The observation and analysis show that the twisted and bending POF can produce higher sensitivity of 30% compared to 21% for bending only and 12% for twisted only than single POF without twisting and bending. High sensitivity macro and micro bending sensors can be highly sensitive to changes in liquid level since the bending causes variation in the light. This project has contributed valuable insights into the use of twisted POFs for enhanced liquid level sensing capabilities.

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AUTHOR CONTRIBUTIONS STATEMENT

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Hazura Haroon		✓				✓		✓	✓	✓	✓	✓		
Hanim Abdul Razak	✓		✓	✓			✓			✓	✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state there is no conflict of interest that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that supports the findings of this study are available from the corresponding author, [initials: SKI], upon reasonable request.

REFERENCES

[1] M. de F. F. Domingues and A. Radwan, "Optical fiber sensors in IoT," in *SpringerBriefs in Electrical and Computer Engineering. Cham: Springer International Publishing*, pp. 73–86, 2017, doi: 10.1007/978-3-319-47349-9_5.

[2] V. Shenoy and S. K. Venkata, "An in-depth analysis of liquid level measurement techniques and performance evaluation using computational fluid Dynamics," *Journal of Sensors*, vol. 2025, no. 1, 2025, doi: 10.1155/js/4412250.

[3] H. S. Munawar, A. W. A. Hammad, and S. T. Waller, "Remote sensing methods for flood prediction: a review," *Sensors*, vol. 22, no. 3, p. 960, 2022, doi: 10.3390/ s22030960.

[4] E. Zahir, S. Das, M. H. Rabbi, S. Huq, and M. B. Hossain, "Implementation of a fiberoptic sensor to detect change in liquid level and change in concentration of solute in a water reservoir," in *1st International Conference on Robotics, Electrical and Signal Processing Techniques, ICREST 2019*, Dhaka, Bangladesh, Jan. 2019, pp. 258–262, doi: 10.1109/ICREST.2019.8644344.

[5] X. Chi, X. Wang, and X. Ke, “Optical fiber–based continuous liquid level sensor based on rayleigh backscattering,” *Micromachines*, vol. 13, no. 4, p. 633, 2022, doi: 10.3390/ mi13040633.
[6] K. R. Sohn and J. H. Shim, “Liquid-level monitoring sensor systems using fiber Bragg grating embedded in cantilever,” *Sensors and Actuators, A: Physical*, vol. 152, no. 2, pp. 248–251, 2009, doi: 10.1016/j.sna.2009.04.003.
[7] T. Guo *et al.*, “Temperature-insensitive fiber Bragg grating liquid-level sensor based on bending cantilever beam,” *IEEE Photonics Technology Letters*, vol. 17, no. 11, pp. 2400–2402, 2005, doi: 10.1109/LPT.2005.857985
[8] C. W. Lai, Y. L. Lo, J. P. Yur, and C. H. Chuang, “Application of fiber bragg grating level sensor and Fabry-Pérot pressure sensor to simultaneous measurement of liquid level and specific gravity,” *IEEE Sensors Journal*, vol. 12, no. 4, pp. 827–831, 2012, doi: 10.1109/JSEN.2011.2161075.
[9] B. Yun, N. Chen, and Y. Cui, “Highly sensitive liquid-level sensor based on etched fiber bragg grating,” *IEEE Photonics Technology Letters*, vol. 19, no. 21, pp. 1747–1749, 2007, doi: 10.1109/LPT.2007.905093.
[10] S. Khaliq, S. W. James, and R. P. Tatam, “Fiber-optic liquid-level sensor using a long-period grating,” *Optics Letters*, vol. 26, no. 16, pp. 1224–1226, 2001, doi: 10.1364/ol.26.001224.
[11] Y. Huang, B. Chen, G. Chen, H. Xiao, and S. U. Khan, “Simultaneous detection of liquid level and refractive index with a long-period fiber grating based sensor device,” *Measurement Science and Technology*, vol. 24, no. 9, 2013, doi: 10.1088/0957-0233/24/9/095303.
[12] H. Liu, H. Liang, M. Sun, K. Ni, and Y. Jin, “Simultaneous measurement of humidity and temperature based on a long-period fiber grating inscribed in fiber loop mirror,” *IEEE Sensors Journal*, vol. 14, no. 3, pp. 893–896, 2014, doi: 10.1109/JSEN.2013.2290837.
[13] T. Lü and S. Yang, “Extrinsic Fabry-Perot cavity optical fiber liquid-level sensor,” *Applied Optics*, vol. 46, no. 18, pp. 3682–3687, 2007, doi: 10.1364/AO.46.003682.
[14] M. Karhan, “Experimental investigation of wettability and evaporation for the surface of PMMA dielectric material used in high-voltage applications and outdoor electrical applications,” *Applied Physics A: Materials Science and Processing*, vol. 127, no. 6, p. 462, 2021, doi: 10.1007/s00339-021-04630-6.
[15] H. Golnabi and P. Azimi, “Design and performance of a plastic optical fiber leakage sensor,” *Optics and Laser Technology*, vol. 39, no. 7, pp. 1346–1350, 2007, doi: 10.1016/j.optlastec.2006.11.003.
[16] L. Liu, S. Deng, J. Zheng, L. Yuan, H. Deng, and C. Teng, “An enhanced plastic optical fiber-based surface plasmon resonance sensor with a double-sided polished structure,” *Sensors*, vol. 21, no. 4, pp. 1–12, 2021, doi: 10.3390/s21041516.
[17] R. He, C. Teng, S. Kumar, C. Marques, and R. Min, “Polymer optical fiber liquid level sensor: a review,” *IEEE Sensors Journal*, vol. 22, no. 2, pp. 1081–1091, 2022, doi: 10.1109/JSEN.2021.3132098.
[18] P. Xue, H. Bao, B. Wu, and J. Zheng, “Fabrication of a screw-shaped plastic optical fiber for liquid level measurement,” *Optical Fiber Technology*, vol. 57, 2020, doi: 10.1016/j.yofte.2020.102237.
[19] B. D. Waluyo, J. S. Rambey, and M. A. R. S, “Plastic optical fiber as water-level sensor,” *Journal of Electrical and Electronic Engineering (JEEE-UMSIDA)*, vol. 7, no. 2, pp. 129–135, 2023, doi: 10.21070/jeeeu.v7i2.1674.
[20] N. Jing, C. Teng, J. Zheng, G. Wang, Y. Chen, and Z. Wang, “A liquid level sensor based on a race-track helical plastic optical fiber,” *IEEE Photonics Technology Letters*, vol. 29, no. 1, pp. 158–160, 2017, doi: 10.1109/LPT.2016.2630730.
[21] C. Teng *et al.*, “Refractive index sensor based on twisted tapered plastic optical fibers,” *Photonics*, vol. 6, no. 2, 2019, doi: 10.3390/photonics6020040.
[22] S. Deng, F. Yu, H. Deng, L. Yuan, and C. Teng, “Twisted tapered plastic optical fibers for continuous liquid level sensing,” *Optical Fiber Technology*, vol. 59, 2020, doi: 10.1016/j.yofte.2020.102318.
[23] Y. Zhang *et al.*, “An optical fiber liquid level sensor based on side coupling induction technology,” *Journal of Sensors*, vol. 2018, 2018, doi: 10.1155/2018/2953807.
[24] J. Mathew, Y. Semenova, and G. Farrell, “A fiber bend-based humidity sensor with a wide linear range and fast measurement speed,” *Sensors and Actuators, a: Physical*, vol. 174, no. 1, pp. 47–51, 2012, doi: 10.1016/j.sna.2011.11.029.
[25] P. R. Watekar, S. Ju, Y. S. Yoon, Y. S. Lee, and W.T. Han, “Design of a trenched bend insensitive single mode optical fiber using spot size definitions,” *Optics Express*, vol. 16, no. 18, p. 13545, 2008, doi: 10.1364/oe.16.013545.
[26] A. Vijayan, S. Gawli, A. Kulkarni, R. N. Karekar, and R. C. Aiyer, “An optical fiber weighing sensor based on bending,” *Measurement Science and Technology*, vol. 19, no. 10, 2008, doi: 10.1088/0957-0233/19/10/105302.
[27] H. Golnabi and N. Aghighi, “Investigation of rolling loss mechanisms in plastic optical fibers,” *Journal of Applied Sciences*, vol. 11, no. 20, pp. 3482–3489, 2011, doi: 10.3923/jas.2011.3482.3489.
[28] C. Unger and W. Stocklein, “Investigation of the microbending sensitivity of fibers,” *Journal of Lightwave Technology*, vol. 12, no. 4, pp. 591–596, 1994, doi: 10.1109/50.285350.
[29] D. Đonlagić and M. Završnik, “Fiber-optic microbend sensor structure,” *Optics Letters*, vol. 22, no. 11, p. 837, 1997, doi: 10.1364/OL.22.000837.
[30] C. R. Zhao, “Fiber-optic aircraft fuel level measurement based on light leakage in optical fiber (in Chinese: Jī yú guāng xiè lòu yuán lǐ de guāng xiān shì fēi jī rán yóu yè wèi cè liáng fāng fǎ yán jiū),” Ph.D. dissertation, Huazhong Univ. of Sci. and Technol., Wuhan, China, 2013.
[31] J. B. Rosolem *et al.*, “Fiber optic bending sensor for water level monitoring: development and field test: A review,” *IEEE Sensors Journal*, vol. 13, no. 11, pp. 4113–4120, 2013, doi: 10.1109/JSEN.2013.2278074.
[32] Y. L. Hou *et al.*, “Polymer optical fiber twisted macro-bend coupling system for liquid level detection,” *Optics Express*, vol. 22, no. 19, p. 23231, 2014, doi: 10.1364/oe.22.023231.
[33] H. Zhang *et al.*, “Optical fiber liquid level sensor based on macro-bending coupling,” *Optical Fiber Technology*, vol. 24, pp. 135–139, 2015, doi: 10.1016/j.yofte.2015.05.012.

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