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An Impedance Stable Bioinspired Tulip Shaped Ultra-Wideband Horn Antenna for Water Characteristic Analysis Using Microwave Technique

Mikrodalga Tekniği Kullanarak Su Karakteristiği Analizi İçin Empedansı Kararlı Biyomimari Lale Şeklinde Ultra Geniş Bant Horn Anteni

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Abstract

In this study, a novel antenna design is presented and characterized to investigate its suitability in water pollution detection applications. The antenna exhibits excellent performance in meeting the stringent requirements of the Federal Communications Commission (FCC) for Ultra-Wideband (UWB) communications. The proposed antenna's return loss conforms to the FCC UWB specifications. At a resonant frequency of 6.34 GHz, the minimum return loss value is -27.236 dB. The proposed antenna's Voltage Standing Wave Ratio (VSWR) characteristics are illustrated with the minimum VSWR value displayed in linear scale. Furthermore, the real and imaginary parts of the antenna impedance are provided to reveal their stability within the UWB frequency range of 3.1-10.6 GHz. Notably, the antenna resistance remains constant, while the antenna reactance approaches zero. These impedance characteristics make the antenna a promising candidate for achieving a perfect match condition when used as a sensor for water pollution detection. The radiation patterns of the proposed antenna are detailed at the UWB center frequency of 6.85 GHz. These patterns display a primary radiation direction at 20 degrees, a main lobe magnitude of 8 dBi, and a side lobe level of -3.9 dB. These features make the antenna well-suited for water pollution detection applications where precise, UWB signal transmission and reception are crucial. Thus, this proposed antenna design offers promising prospects for enhancing the efficiency and accuracy of water pollution detection systems.

Keywords: Antenna Design, Ultra-Wideband (UWB), Impedance Stability, Sensor, Water Quality Monitoring.

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Özet

Bu çalışmada, su kirliliği tespit uygulamalarında uygunluğunu araştırmak için yeni bir anten tasarımı sunulmuş ve karakterize edilmiştir. Anten, Ultra Geniş Bant (UWB) iletişimi için Federal İletişim Komisyonu'nun (FCC) gereksinimlerini karşılamada uygun bir performans göstermektedir. Önerilen antenin geri dönüş kaybı, FCC UWB kıstaslarına uygun olduğu saptanmıştır. 6.34 GHz rezonans frekansında, minimum geri dönüş kaybı değeri -27.236 dB'dir. Önerilen antenin Voltaj Duran Dalga Oranı (VDDR) özellikleri, doğrusal ölçekte görüntülenen minimum VSWR değeri ile gösterilmiştir. Ayrıca, anten empedansının gerçek ve sanal kısımları, 3.1-10.6 GHz UWB frekans aralığında kararlılıklarını ortaya çıkarmak için sağlanmıştır. Özellikle, anten reaktansı sıfıra yaklaşırken anten direnci sabit kalır. Bu empedans özellikleri, anteni su kirliliği tespiti için bir sensör olarak kullanıldığında uygun bir eşleşme koşulu elde etmek için umut verici bir tasarım haline getirmektedir. Önerilen antenin ışıma örüntü modelleri, 6.85 GHz'lik UWB merkez frekansında detaylandırılmıştır. Bu ışıma örüntüsü modeli, 20 derecede bir birincil radyasyon yönü, 8 dBi bir ana lob büyüklüğü ve -3.9 dB'lik bir yan lob seviyesi göstermektedir. Bu özellikler, anteni hassas, UWB sinyal iletimi ve alımının çok önemli olduğu su kirliliği algılama uygulamaları için çok uygun hale getirdiği farklı performans paramterleri ile de analiz edilmiştir. Bu nedenle, önerilen bu anten tasarımı, su kirliliği tespit sistemlerinin verimliliğini ve doğruluğunu artırmak için umut verici beklentiler sunmaktadır.

Anahtar Kelimeler: Anten Tasarımı, Ultra Geniş Bant (UWB), Empedans Kararlılığı, Sensör, Su Kalitesi İzleme.

1. INTRODUCTION

Bio-inspired antennas have gained considerable interest in recent years due to their effective designs and attributes inspired by nature. These antennas resemble the structures, shapes, and functionalities observed in various organisms, which offers a manner to develop performance and efficacy throughout a myriad of applications. One scope where bio-inspired antennas are conducted is in Ultra-Wideband applications [1-7]. Ultra-wideband systems perform a broad frequency range, which facilitates transmitting and receiving the signals. This feature is applicable for high-resolution imaging [8-11], precise sensing [12-14], and accurate signal [15] in diverse applications. One crucial profit of bio-inspired antennas in UWB applications hinges on their capability to launch high-resolution imaging. By resembling structures found in nature, such as the compound eyes of insects or the sonar systems of bats, bio-inspired antennas are capable of enhancing the spatial resolution for UWB imaging systems. This powerful resolution helps the detection of fine details and subtle environmental changes. This condition makes bio-inspired UWB antennas fundamental tools in fields like medical imaging, environmental monitoring, and security systems. Furthermore, bio-inspired antennas provide benefits such as perimeter improvement, fractality, and flexibility, which makes them greatly superior for antenna engineers and researchers. Moreover, bio-inspired antennas have been widely scrutinized in the advancement of compact multi-band antennas, since these types of structures showcase their versatility and potential applications across different frequency bands. As of the literature survey about the potential of bio-inspired antennas in UWB applications, it is clear that they provide a favorable design technique to fulfill the requirements of modern wireless technologies owing to their enhanced performance, efficiency, and high-resolution imaging capabilities [1-

23]. UWB technology operates across a broad frequency range, spanning from a few hundred megahertz to several gigahertz. This broad spectrum allows for the transmission and reception of signals with large bandwidths, enabling high-resolution imaging, precise sensing, and accurate signal detection in diverse applications. Bio-inspired antennas, when integrated into UWB systems, bring several advantages that make them particularly well-suited for such applications. One pivotal advantage of bio-inspired antennas in UWB applications lies in their capability to deliver high-resolution imaging [8-11, 15, 24]. For example, bio-inspired UWB antennas are able to non-invasively monitor vital signs including respiration and heartbeat rates [24]. Moreover, they are also able to be utilized in environmental monitoring to sense temperature, humidity, or air quality. In addition, bio-inspired antennas offer the advantages of adaptability and versatility. This adaptability enables the optimization of antenna performance and the customization of UWB systems for specific applications, such as water monitoring or wireless communication [25-32].

In brief bioinspired antennas play a key role in UWB employment offering unique nature-inspired designs and features. These antennas provide high-resolution images, enhanced sensing capabilities, and the ability to accommodate to specific application requirements. Integrating bioinspired antennas into UWB systems has the potential to revolutionize various fields, including medicine, environmental monitoring, and wireless communications. Further research and development in this field direct to ascertain the full potential of bioinspired antennas in UWB applications, driving technological advancements and amending our understanding and interaction with the world. This study foregrounds the potential impact of bioinspired UWB antenna technology and simplicity to revolutionize our approach to water quality assessment and pollution detection.

2. MATERIALS AND METHODS

2.1. Bioinspired Tulip-Shaped UWB Antenna Geometry

In this study, the bio-inspired tulip-shaped antenna is proposed as a fascinating innovation in antenna design and is inspired by the elegant shape of the tulip flower. The proposed design of this antenna structure incorporates similar curves and shapes into its structure as the tulip's petals gently curve and spread outward. The proposed geometry of the tulip-shaped antenna serves to improve radiation patterns. It can generate directed radiation patterns with controlled beam width, which is vital for applications like point-to-point communication and radar systems. The bioinspired tulip-shaped antenna has a wide range of applications. It is widely used in wireless communication systems, microwave imaging, radar technology, UWB communication, and other applications. Figure 1 presents the various perspectives of the bioinspired UWB horn antenna structure designed with CST Microwave Studio. A discrete port with 50Ω impedance is utilized.

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The antenna is etched on the flexible copper material to yield flexibility to the system. Overall physical parameters are tabulated in Table 1.

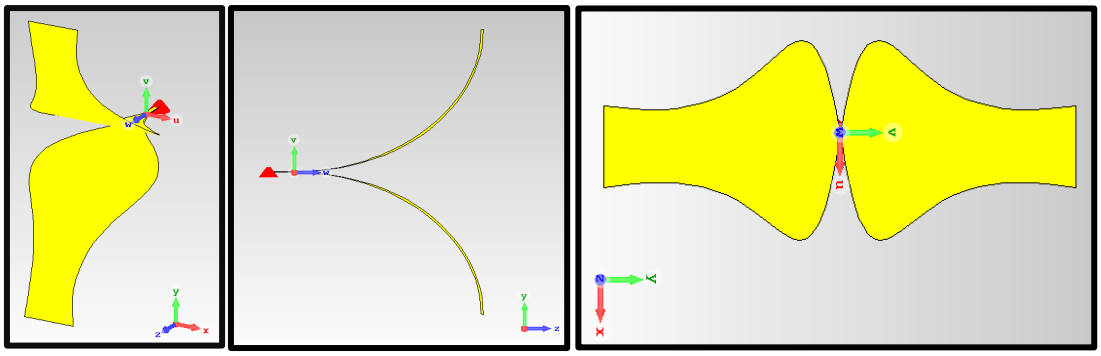

Figure 1: The proposed bioinspired flexible antenna views

Table 1-Physical Parameters of the proposed of bioinspired UWB antenna

Physical Parameters	Values(mm)
Aperture Width	20.52
Aperture Height	118.29
Feed Width	1.96
Feed Height	0.32
Feed_ Length	10.77
Plate Width 1	8.53
Plate Width 2	25.29
Plate Width 3	42.94
Plate Width 4	50.55
Plate Width 5	46.02
Plate Width 6	34.75
Plate Width 7	24.94
Plate Width 8	19.52
Plate Width 9	18.45
Plate Length:1,2,3,4,5,6,7,8,9,10	10.77
Plate Separation:1,2,3,4,5,6,7,8,9	1.53

3. RESULTS AND DISCUSSIONS

Figure 2 displays the reflection coefficient of the proposed bioinspired UWB antenna. As Figure 2 indicates that the reflection coefficient of the proposed antenna is acceptable along with UWB requirements defined by FCC. Figure 3 also depicts the minimum reflection coefficient return loss value which occurs at 6.34 GHz. The numerical value of the minimum return loss value is -27.236 dB as shown in Figure 3. Additionally, Figure 4 presents the VSWR characteristic of the proposed antenna. Then, Figure 5 illustrates the minimum VSWR value in linear scale.

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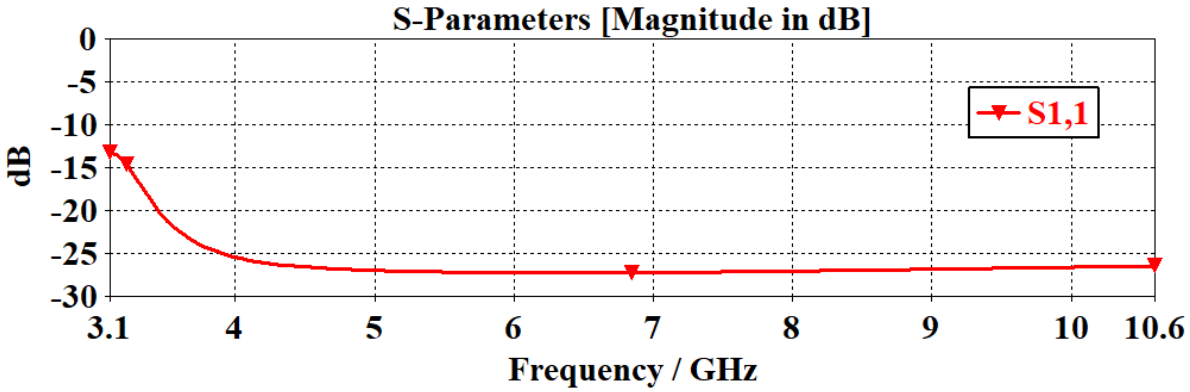

Figure 2: Reflection coefficient characteristic of the bioinspired UWB antenna

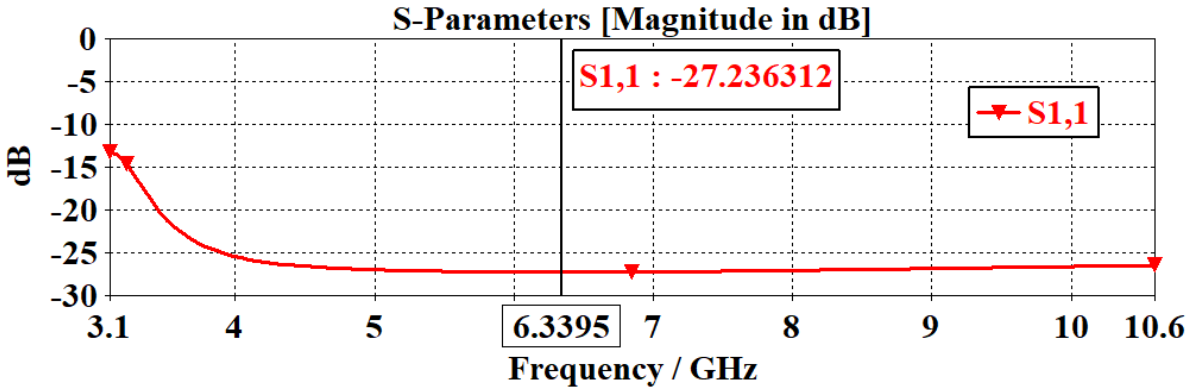

Figure 3: Minimum return loss value in dB scale of the bioinspired UWB antenna

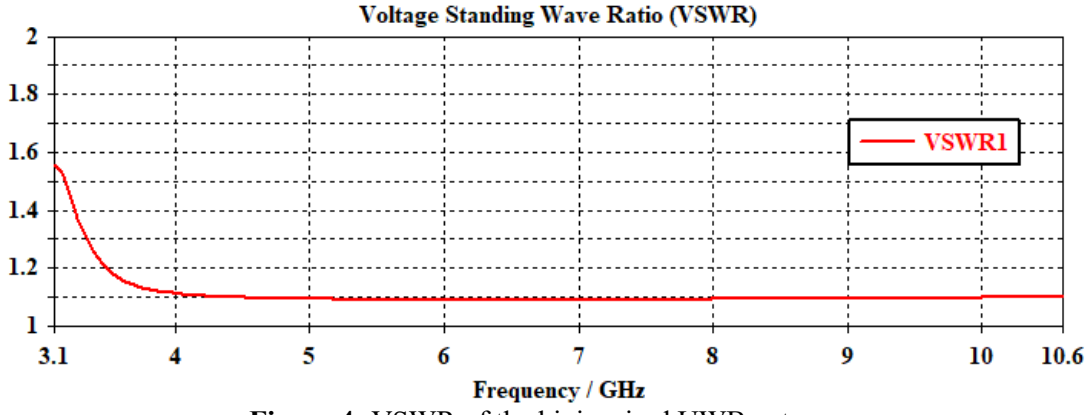

Figure 4: VSWR of the bioinspired UWB antenna

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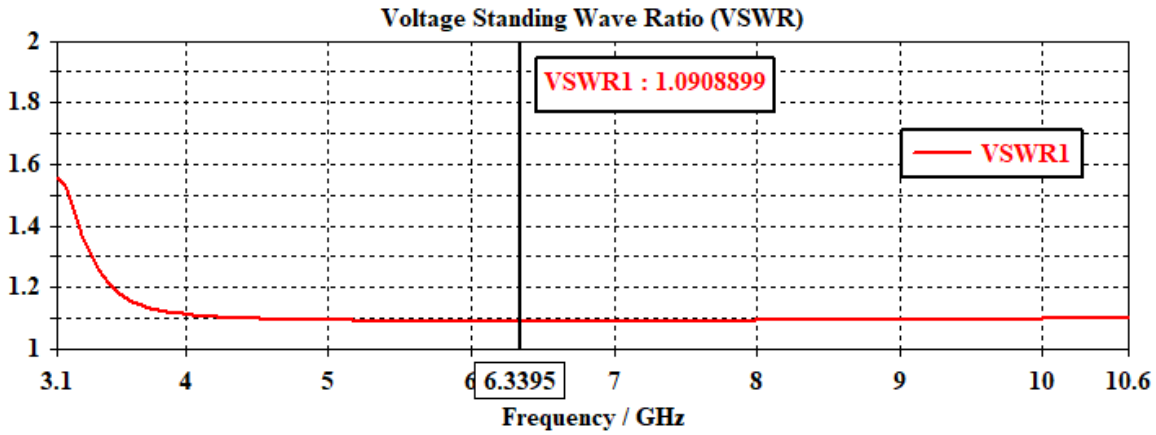

Figure 5: Minimum VSWR value of the bioinspired UWB antenna

The real and imaginary parts of the proposed antenna are shown in Figure 6. The solid line with circles, which stands for the real part of the antenna impedance, and the dashed line with circles, which stands for imaginary part of the antenna impedance. It is clear from Figure 6 that both imaginary and real parts are almost stable in the desired frequency range of interest. Besides, it is apparent that the antenna resistance is of nearly 50Ω and the antenna reactance is approximately zero in the frequency range spanning from 3.1 to 10.6 GHz. Thus, the load impedance or transmission line impedance can be adjusted by using different impedance matching techniques to fulfill perfectly match condition.

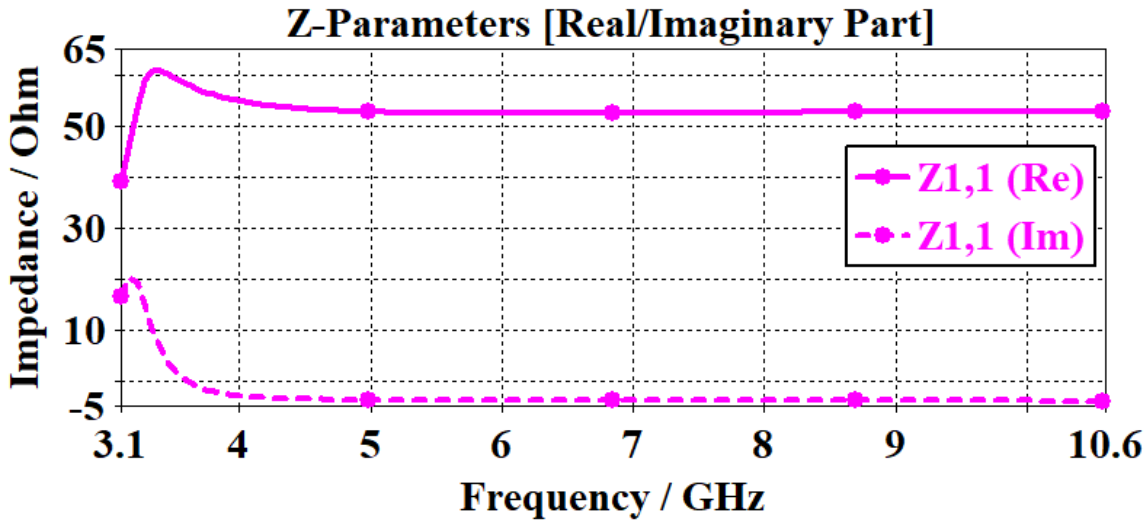

Figure 6: Real and imaginary parts of the bioinspired UWB antenna impedance

Figure 7a visualizes the radiation pattern of the proposed bioinspired UWB horn antenna along with cartesian representation at the UWB center frequency of 6.85 GHz. Figure 7b also shows the polar representation of the radiation pattern at the frequency of 6.85 GHz. It is clear from Figure 7a-b that the main lobe direction occurs at 20°, the main lobe magnitude is 8dBi, and side lobe level is -3.9 dB.

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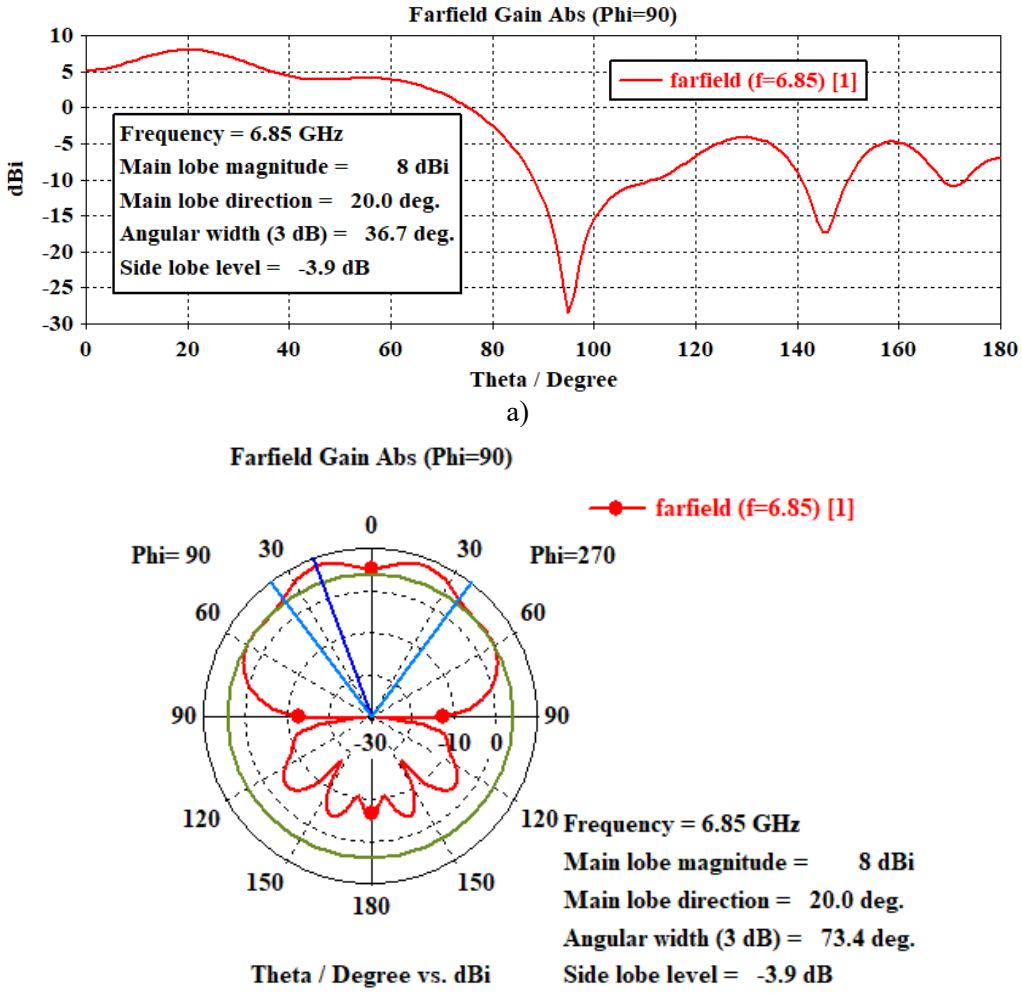

Figure 7: The Cartesian representation of the radiation pattern at 6.85 GHz

4. CONCLUSION

This study offers a distinctive Ultra-Wideband (UWB) horn antenna design that's bioinspired and designed specifically for water pollution detection applications. The performance of the antenna has been meticulously evaluated, and the following findings are made. The Federal Communications Commission (FCC) has set tough UWB specifications, which the proposed antenna fulfills. These requirements are suitable for its return loss characteristics. In addition, for water pollution detection systems, this antenna performance parameter guarantees trusted UWB communication. The suggested antenna maintains a stable impedance over the UWB frequency range of 3.1-10.6 GHz, according to the Voltage Standing Wave Ratio (VSWR) characteristics. Impedance matching can be effectively achieved because the resistance stays constant and the reactance gets close to zero. The radiation pattern parameter, which provides precise directional sensitivity, is also appropriate for the detection of water pollution. For this reason, the suggested

antenna's precise radiation patterns and stable impedance characteristics make it a great option for applications involving the detection of water pollution. Its ability to function in the UWB spectrum guarantees precise data transmission and reception, which enhances the efficacy of systems for water quality assessment and environmental monitoring. Because of this, the suggested antenna design described in this study exhibits excellent stability in impedance characteristics and ideal radiation patterns, in addition to meeting the FCC's UWB requirements. These qualities make it an invaluable instrument for improving the accuracy and consistency of water pollution identification, and supporting continued efforts to protect our ecosystem and water supplies. For practical installation, additional experimental validation and integration into water quality monitoring systems are recommended.

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