Analysis of Acoustic Channel Characteristics in Shallow Water Based on Multipath Model

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Abstract. In the shallow water environment, the water surface, and the seafloor act as reflective boundaries for the sound waves. When a sound wave encounters these boundaries, it undergoes reflection, bouncing back and forth between the surface and the bottom. As a result, the sound energy is distributed among various paths, leading to multipath arrivals at the receiver. The repeated reflections contribute to the complexity of the sound propagation in shallow water. This multipath propagation can cause interference and fading, making the received signals challenging to decode, interpret accurately, and transmission losses. Therefore, proper modelling of channel is essential inoreder to deploy a network with high accuracy. In this work, we have developed and analyzed an acoustic multipath channel model to investigate the impact of mixed layer depth and near field anomaly on transmission losses in underwater environments. The main focus is on understanding how various underwater medium parameters, such as temperature, salinity, depth, and pH, affect the transmission losses. It is evident from simulation results; acoustic velocity has increased by 30 m/s when the temperature reduced from 30 °C to 14 °C and 7 m/s when the salinity increased from 30 ppt to 35 ppt. Transmission losses are increased by 58.8% when the mixed layer depth (*MLD*) increased from 10 m to 95 m. Whereas, these losses are reduced by 43.7% when the near field anomaly (K_L) increased from 7 dB to 20 dB.

Keywords: Acoustic Channel · Multipath · Reflection · Sound Speed · Temperature · Transmission Loss · Salinity

1 Introduction

Underwater Acoustic Sensor Networks (UASNs) are specialized networks that utilize underwater acoustic communication for data gathering, monitoring, and collaboration in underwater environments [1]. UASNs consist of a collection of autonomous or semi-autonomous underwater sensor nodes that work together to perform various tasks such

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as oceanographic data collection, environmental monitoring, underwater surveillance, and underwater exploration [2]. UASNs play a crucial role in expanding our understanding of underwater ecosystems, oceanography, and marine resources. They enable real-time monitoring of underwater phenomena, such as temperature, salinity, water quality, marine life, and seabed conditions. By collecting and transmitting data from diverse underwater locations, UASNs provide valuable insights into underwater processes and enable timely decision-making for various applications [3]. The unique characteristics of underwater environments pose significant challenges for UASNs [4, 5]. Underwater acoustic communication is the primary means of data transmission in UASNs since radio frequency signals do not propagate efficiently in water due to high absorption and attenuation. Acoustic signals can travel long distances, but they suffer from limited bandwidth, high propagation delays, multipath fading, and significant signal attenuation, which can affect the performance and reliability of underwater communication systems [6, 7].

To address these challenges, UASNs require specialized hardware and networking protocols [8]. Acoustic modems are used as communication interfaces, employing techniques such as frequency modulation, spread spectrum, and advanced error correction coding to enhance the reliability and data rate of underwater acoustic communication. UASNs also employ advanced signal processing algorithms and networking protocols specifically designed for underwater environments to mitigate the effects of multipath propagation, interference, and limited bandwidth. Multipath propagation is a significant phenomenon that affects UASNs and their communication performance [9]. It is primarily caused by the interaction of sound waves with the underwater environment, including factors such as reflections, refractions, and scattering. Through a sequence of repeated reflections from both the water's surface and the seabed, sound travels vast distances in shallow water. Due to these reflections, sound waves might propagate through many routes before they are detected by a receiver.

The seabed and the water surface serve as sound waves reflecting limits in an environment with shallow water. These barriers cause a sound wave to reflect, causing it to bounce back and forth between the surface and the bottom. The sound energy is thus dispersed along a number of routes, resulting in multipath arrivals to the receiver. Sound transmission in shallow water is difficult due to the recurrent reflections. The arrival timings, amplitudes, and phases of the signals that are received can vary depending on the trajectories that the sound waves follow, as well as their lengths and travel periods [10]. The interference and fading that might result from this multipath propagation make it difficult to decode and correctly understand the signals that are received. Designing and enhancing underwater communication systems and acoustic signal processing algorithms requires an understanding of and consideration for the multipath propagation phenomena in shallow water [11].

2 Related Work

The emergence of Underwater Acoustic Sensor Networks (UASNs) has garnered considerable interest in various fields, thanks to their wide range of applications in underwater monitoring, environmental sensing, marine exploration, and military surveillance. In the context of UASNs, understanding and addressing transmission losses are vital for achieving reliable and efficient communication in underwater environments. Extensive research papers and studies have been dedicated to exploring the factors that influence transmission losses in UASNs. These include path loss models, absorption and scattering effects, multipath propagation phenomena, channel estimation and equalization techniques, as well as network topology and routing considerations. By investigating and comprehending these factors, researchers aim to enhance the performance and effectiveness of UASNs by mitigating transmission losses and optimizing communication strategies.

This research contributes to the advancement of underwater communication systems, enabling them to operate successfully in challenging underwater conditions and fulfill their potential in diverse applications. In [12], the authors have investigated the fundamental physics of wave propagation, specifically focusing on acoustic, electromagnetic (EM), and optical communication carriers. In [13], the authors have extensively studied the impact of propagation characteristics on underwater communication. In [14], the authors have focused on the relationship between propagation loss, ambient noise, and channel capacity in underwater communication. To address inaccuracies in sound speed estimation in oceans and seas, a mathematical model [15] has been proposed. This model provides a conversion framework between atmospheric pressure and depth, as well as depth and atmospheric pressure, aiding in sound speed determination. In [16], the authors have presented an experimental setup that investigates the impact of underwater medium parameters.

A method [17] has been proposed to enhance localization accuracy in underwater environments. To simulate underwater networks effectively, a specifically developed acoustic channel model [18] is employed. In [19], researchers have conducted real-time measurements of route loss in underwater acoustic channels. In [20], a deep learning-based framework has been introduced to enhance accuracy and throughput in channel modeling. The authors have provided a detailed account of the statistical properties of the channel model in [21]. Moreover, a novel technique for frame boundary estimation in UASN has been proposed in [22]. In [23], the authors especially address the clustering in UASN by focusing on the integration of three essential approaches in the context of IoT applications. In [24], the authors investigated how water absorption affected the hybrid phenol formaldehyde (PF) composites' mechanical characteristics.

3 Methodology

This comprehensive approach provides valuable insights into the complex acoustic environment of shallow and deep water, and enabling better understanding and modeling of underwater acoustic propagation.

3.1 Sound Speed

The transmission of sound through water differs significantly from electromagnetic (EM) waves, primarily due to its slow speed [25, 26]. Mackenzie's empirical formula, denoted by (1), provides a means to calculate sound velocity.

$$c(T, S, z) = a_1 + a_2 T + a_3 T^2 + a_4 T^3 + a_5 (S - 35) + a_6 z + a_7 z^2 + a_8 T (S - 35) a_9 T z^3 \quad (1)$$

3.2 Acoustic Propagation loss

Propagation loss of sound refers to the reduction in the strength or intensity of sound waves as they travel through a medium or propagate in a given environment [27]. The loss associated with cylindrical spreading is expressed using Eq. (2), while spherical spreading loss is represented by Eq. (3).

$$L_{CS} = 10 \times \log(R_t) \tag{2}$$

$$L_{SS} = 20 \times \log(R_t) \tag{3}$$

3.3 Absorption Loss

Sound waves in a medium, such as air or water, experience absorption, where the energy of the sound wave is converted into heat [28]. The absorption is frequency-dependent, with higher frequencies generally being absorbed more rapidly which is represented using (4). Where, α is absorption coefficient in underwater, it represents the rate at which sound energy is converted into other forms, such as heat, due to the inherent properties of the water medium. The absorption coefficient is frequency-dependent, meaning that different frequencies of sound waves are absorbed to varying degrees. Higher frequencies generally experience greater absorption than lower frequencies. The absorption coefficient is represented using (5). Where, A_1 and A_2 represent the contributions of boric acid and magnesium sulphate components, respectively, in sea water. Similarly, P_1, P_2, and P_3 denote the depth pressure components for boric acid, magnesium sulphate, and pure water, respectively. The relaxation frequency for boric acid, denoted as f_1 (in kHz), is given by Eq. (6). In Eq. (6), S represents salinity (in parts per 1000), and T represents temperature in degrees Celsius. The relaxation frequency for magnesium sulfate, denoted as f_2 (in kHz), is given by Eq. (7).

$$L_{ab} = (\alpha \times R_t) \times 10^{-3} \tag{4}$$

$$\alpha = \frac{A_1 P_1 f_1 f^2}{f^2 + f_1^2} + \frac{A_2 P_2 f_2 f^2}{f^2 + f_2^2} + A_3 P_3 f^2 \tag{5}$$

$$f_1 = 2.8\left(\frac{S}{35}\right)^{0.5} \times 10^{[4-1245/(273+T)]} \tag{6}$$

$$f_2 = \frac{8.17 \times 10^{[8-1990/(273+T)]}}{1 + 0.0018(S - 35)} \tag{7}$$

3.4 Transmission Loss

In shallow water, sound travels a long way by repeatedly reflecting off the bottom and surface, a process known as multipath propagation [29]. This phenomenon introduces transmission losses. The equation employed in this analysis accounts for the horizontal separation distance (r) between the sound source and receiver, specifically when r is within a range of up to 1 times H (skip distance). In this context, H represents the average water depth of the acoustic study area, which serves as a conservative definition for the purposes of this analysis (skip distance). The skip distance H can be defined by using (8). The transmission losses due to multipath in shallow water is defined using (9) for the case, when r is within the range of H, (10) for the case when $H \leq r \leq 8H$ and (11) when $r > 8H$. Where, d is the mixed layer depth, z is the scenario depth, K_L is the near field anomaly, α_T is the shallow water attenuation coefficient [30].

$$H = \sqrt{\frac{1}{3}(d + z)} \tag{8}$$

$$TL_{Multipath} = 20 \times \log(r) + \alpha \times r + 60 - K_L \tag{9}$$

$$TL_{Multipath} = 15 \times \log(r) + \alpha \times r + \alpha_T(r/H - 1) + 5 \times \log(H) + 60 - K_L \tag{10}$$

$$TL_{Multipath} = 10 \times \log(r) + \alpha \times r + \alpha_T(r/H - 1) + 10 \times \log(H) + 60 - K_L \tag{11}$$

4 Simulation Parameters

To simulate the transmission losses of an UASN, several parameters need to be considered for the simulation model which helps in accurately predicting the transmission losses. Table 1 provides the detailed list of parameters used for simulation along with their ranges.

Table 1. Execution Parameters

Parameter	Range
Depth (meters)	0–100
Temperature (°C)	30–12
Salinity (ppt)	30–35
Frequency(kHz)	0.1–100
pH	7.8
R_t (meters)	100
MLD (meters)	10–95
K_L(dB)	7–20

5 Simulation Results

The transmission of underwater acoustics is significantly influenced by the acoustic velocity in shallow water. The speed at which sound travels through water varies with temperature changes. Figure 1 illustrates this relationship, showing that sound speed increases with greater depth but decreases as the water temperature decreases. For instance, at a specific depth of 10 m and a temperature of 30 °C, the initial sound speed is measured to be 1510 m/s. However, when the temperature is lowered to 14 °C while keeping the depth constant, the sound speed increases to 1540 m/s, as shown in Fig. 1. Interestingly, as the depth increases, the sound speed becomes more closely associated with changes in water salinity rather than changes in temperature.

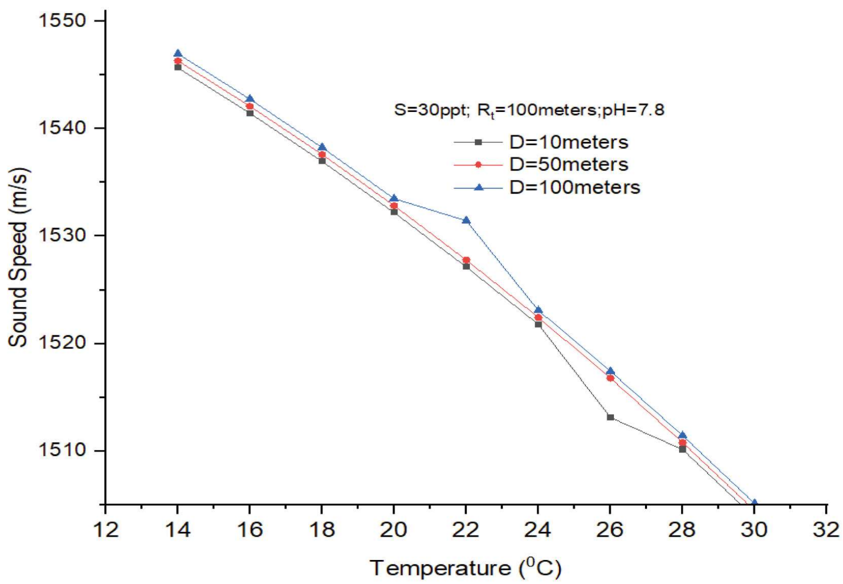

Fig. 1. Acoustic velocity disparities in accordance with temperature in shallow water.

It is observed from Fig. 2, that the salinity variations are also directly proportional to sound speed variations. Higher salinity levels typically result in increased sound speed, while lower salinity levels correspond to decreased sound speed. As the depth increases and salinity levels rise, the sound speed also increases. At a specific salinity ($S = 33$ppt), different sound speed profiles are observed along the depth, ranging from 1534 m/s to 1542 m/s, as depicted in Fig. 2.

The presence of different chemicals in underwater environments can lead to sound absorption. Chemical components such as dissolved gases, salts, and organic matter have distinctive absorption characteristics, influencing the propagation of sound waves in the water medium. These chemicals interact with sound waves, absorbing energy at specific frequencies and resulting in a reduction in sound intensity over distance (see Fig. 3).

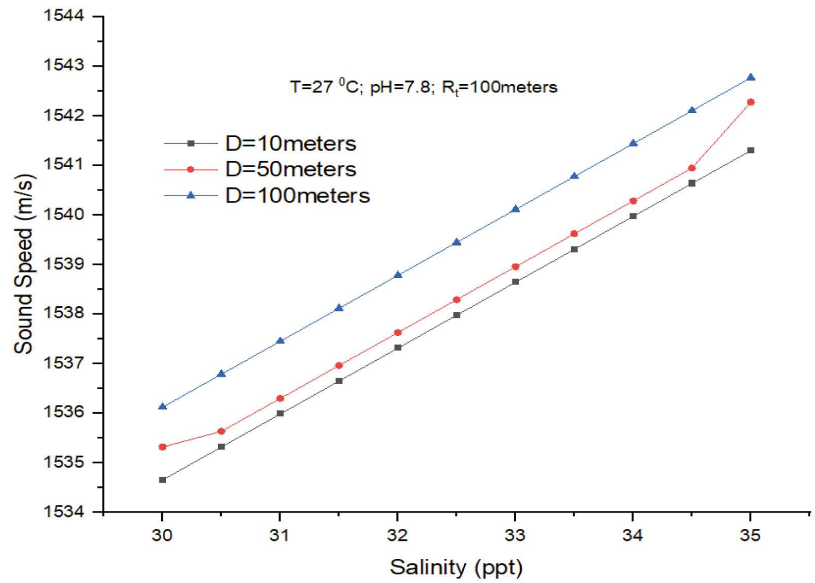

Fig. 2. Acoustic velocity disparities in accordance with salinity in deep water.

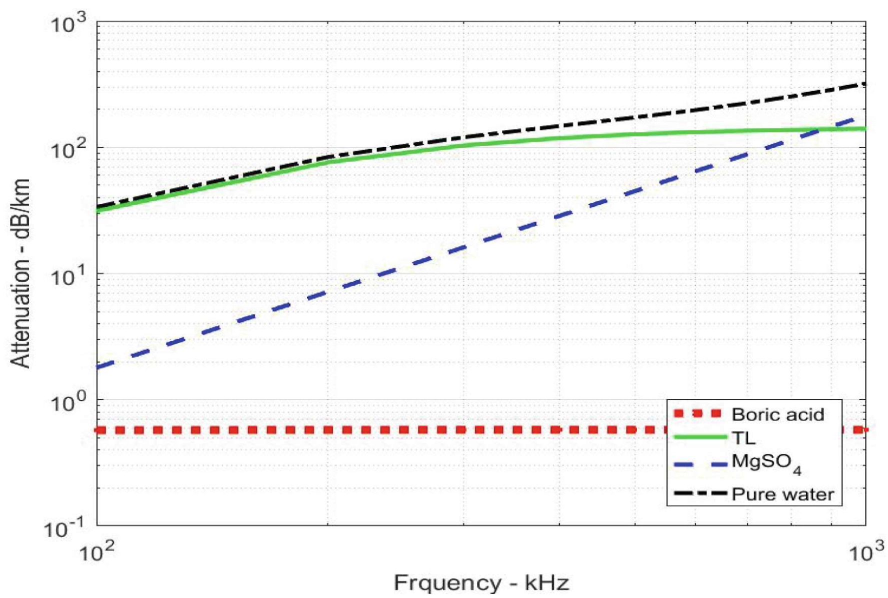

Fig. 3. Frequency *vs* attenuation due to various chemical compositions.

When the mixed layer depth is shallow, it can lead to transmission losses due to high attenuation. Specific impact of mixed layer depth on transmission losses depends on various factors, such as the frequency of the sound waves, the composition of the mixed layer, the characteristics of the seafloor, and the environmental conditions. It is depicted from Fig. 4, that the impact of mixed layer depth on transmission losses under various medium parameters. As the mixed layer depth increase, the transmission losses are also increase for the case of $H \leq r \leq 8H$.

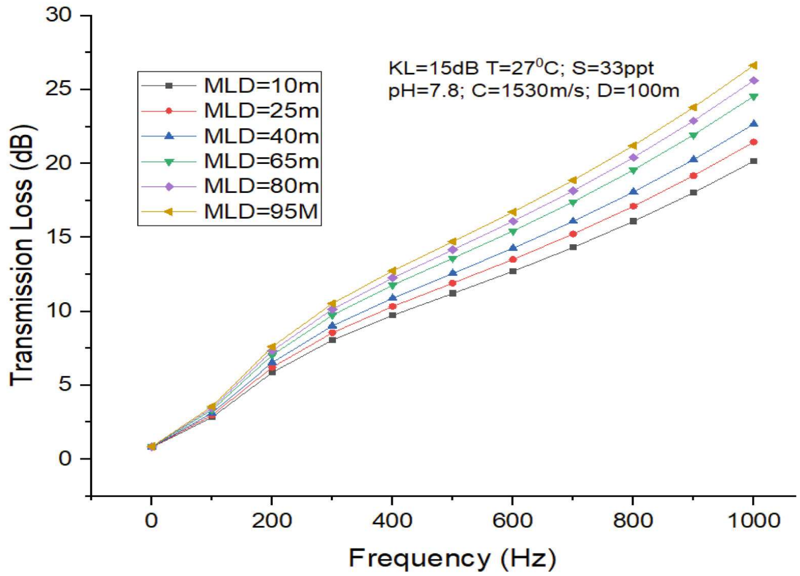

Fig. 4. Transmission Losses in shallow water for multipath model by varying *MLD*.

Near field anomalies occur when sound waves interact with abrupt changes in the water column, such as changes in depth, temperature, salinity, or bottom topography. These anomalies can cause the sound waves to deviate from their expected behavior, resulting in transmission losses. As the value of near field anomaly increase, the transmission losses are reducing gradually (see Fig. 5).

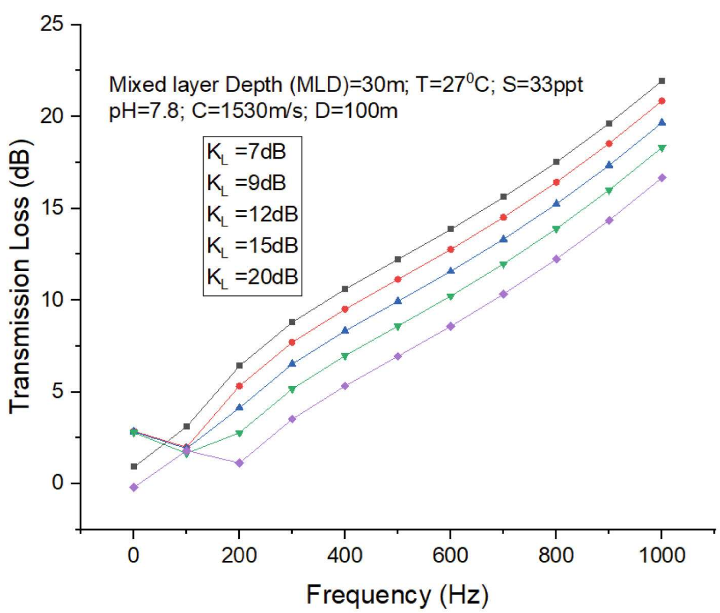

Fig. 5. Transmission Losses in shallow water for multipath model by varying K_L.

6 Conclusion

In this study, we have formulated and examined an acoustic multipath channel model to explore how the mixed layer depth and near field anomaly impact transmission losses in underwater environments. The primary objective is to comprehend the influence of various parameters of the underwater medium, including temperature, salinity, depth, and pH, on transmission losses. Our simulation results reveal intriguing findings. When the temperature decreased from 30 °C to 14 °C, the acoustic velocity increased by 30 m/s. Similarly, a salinity increases from 30 ppt to 35 ppt led to a 7 m/s rise in acoustic velocity. Furthermore, transmission losses surged by 58.8% with an increase in mixed layer depth (*MLD*) from 10 m to 95 m. Conversely, when the near field anomaly (K_L) increased from 7 dB to 20 dB, these losses decreased significantly by 43.7%.

References

1. Sozer, E.M., Stojanovic, M., Proakis, J.G.: Underwater acoustic networks. IEEE J. Ocean. Eng. **25**(1), 72–83 (2000)
2. Akyildiz, I.F., Pompili, D., Melodia, T.: Underwater acoustic sensor networks: research challenges. Ad Hoc Netw. **3**(3), 257–279 (2005)
3. Venkateswara Rao, Ch., Padmavathy, N.: Effect of link reliability and interference on two-terminal reliability of mobile ad hoc network. In: Advances in Data Computing, Communication and Security. Lecture Notes on Data Engineering and Communications Technologies, vol. 106, pp. 555–565(2022)
4. Rao, C.V., Padmavathy, N., Chaturvedi, S.K.: Reliability evaluation of mobile ad hoc networks: with and without interference. In: IEEE 7th International Advance Computing Conference, pp. 233–238 (2017)
5. Barbeau, M., Garcia-Alfaro, J., Kranakis, E., Porretta, S.: The sound of communication in underwater acoustic sensor networks: (position paper). In: Ad Hoc Networks: 9th International Conference, AdHocNets Niagara Falls, ON, Canada, pp. 13–23 (2017)
6. Akyildiz, I.F., Pompili, D., Melodia, T.: Challenges for efficient communication in underwater acoustic sensor networks. ACM SIGBED Rev. Spec. Issue Embed. Sens. Netw. Wireless Comput. **1**(2), 3–8 (2004)
7. Stojanovic, M., Preisig, J.: Underwater acoustic communication channels: propagation models and statistical characterization. IEEE Commun. Mag. **47**(1), 84–89 (2009)
8. Jindal, H., Saxena, S., Singh, S.: Challenges and issues in underwater acoustics sensor networks: a review. In: International Conference on Parallel, Distributed and Grid Computing Solan, pp. 251–255 (2014)
9. Ismail, N.-S., Hussein, L., Syed, A., Hafizah, S.: Analyzing the performance of acoustic channel in underwater wireless sensor network. In: Asia International Conference on Modelling & Simulation, pp. 550–555 (2010)
10. Wanga, X., Khazaiec, S., Chena, X.: Linear approximation of underwater sound speed profile: precision analysis in direct and inverse problems. Appl. Acoust. **140**, 63–73 (2018)
11. Ali, M.M., Sarika, J., Ramachandran, R.: Effect of temperature and salinity on sound speed in the central Arabian sea. Open Ocean Eng. J. **4**, 71–76 (2011)
12. Kumar, S., Prince, S., Aravind, J.V., Kumar, G.S.: Analysis on the effect of salinity in underwater wireless optical communication. Mar. Georesour. Geotechnol. **38**(3), 291–301 (2020)

13. Preisig, J.: Acoustic propagation considerations for underwater acoustic communications network development. Mobile Comput. Commun. Rev. **11**(4), 2–10 (2006)
14. Sehgal, A., Tumar, I., Schonwalder, J.: Variability of available capacity due to the effects of depth and temperature in the underwater acoustic communication channel. In: Oceans 2009-Europe, Bremen, pp. 1–6 (2009)
15. Leroy, C.C., Parthiot, F.: Depth-pressure relationships in the oceans and seas. J. Acoust. Soc. Am. **103**(3), 1346–1352 (1998)
16. Yuwono, N.P., Arifianto, D., Widjiati, E., Wirawan.: Underwater sound propagation characteristics at mini underwater test tank with varied salinity and temperature. In: 6th International Conference on Information Technology and Electrical Engineering (ICITEE), pp. 1–5 (2014)
17. Shi, H., Kruger, D., Nickerson, J.V.: Incorporating environmental information into underwater acoustic sensor coverage estimation in Estuaries. In: MILCOM 2007 - IEEE Military Communications Conference, pp. 1–7 (2007)
18. Morozs, N., Gorma, W., Henson, B.T., Shen, L., Mitchell, P.D., Zakharov, Y.V.: Channel modeling for underwater acoustic network simulation. IEEE Access **8**, 136151–136175 (2020)
19. Lee, H.K., Lee, B.M.: An underwater acoustic channel modeling for Internet of Things networks. Wireless Pers. Commun. **116**(3), 2697–2722 (2020). https://doi.org/10.1007/s11277-020-07817-x
20. Onasami, O., Feng, M., Xu, H., Haile, M., Qian, L.: Underwater acoustic communication channel modeling using reservoir computing. IEEE Access **10**, 56550–56563 (2022)
21. Zhu, X., Wang, C.X., Ma, R.: A 2D Non-stationary channel model for underwater acoustic communication systems. In: IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), pp. 1–6 (2021)
22. Kotipalli, P., Vardhanapu, P.: Frame boundary detection and deep learning-based doppler shift estimation for FBMC/OQAM communication system in underwater acoustic channels. IEEE Access **10**, 17590–17608 (2022)
23. Venkata Lalitha, N., Renu, K., Arun, M., Anandakumar, H., Vijendra Babu, D., Bos Mathew, J.: IoT based energy efficient multipath power control for underwater sensor network. Int. J. Syst. Assur. Eng. Manag. 1–10 (2022)
24. Sekhar, S., et al.: Effects of water absorption on the mechanical properties of hybrid natural fibre/phenol formaldehyde composites. Sci. Rep. **11**(1), 13385 (2021)
25. Etter, P.C.: Underwater Acoustic Modeling and Simulation. CRC Press (2018)
26. Padmavathy, N., Venkateswara Rao, Ch.: Reliability evaluation of underwater sensor network in shallow water based on propagation model. J. Phys. Conf. Ser. **1921**(1), 012018 (2021)
27. Venkateswara Rao, C., Swathi, S., Charan, P.S.R., Santhosh Kumar, C.V., Pathi, A.M.V., Praveena, V.: Evaluation of sound propagation, absorption, and transmission loss of an acoustic channel model in shallow water. In: Congress on Intelligent Systems, pp. 455–465 (2023)
28. Padmavathy, N., Venkateswara Rao, Ch.: Effect of undersea parameters on reliability of underwater acoustic sensor network in shallow water. IOP Conf. Ser. Mater. Sci. Eng. **1272**(1), 012011 (2022)
29. Venkateswara Rao, C., et al.: Analysis of acoustic channel model characteristics in deep-sea water. In: International Conference on Cognitive Computing and Cyber Physical Systems, pp. 234–243 (2023)
30. Venkateswara Rao, C., et al.: Comparison of acoustic channel characteristics in shallow and deep-sea water. In: International Conference on Cognitive Computing and Cyber Physical Systems, pp. 256–266 (2023)

Development of Cost-Effective Water Quality Monitoring for Potable Drinking Water Using IoT

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Abstract. One of the main substances that significantly affects ecosystems is water. Unfortunately, with increased urbanization, sewage, abstraction of chemical fertilizers and pesticides in agriculture, which contaminate water, is now widely exploited. To monitor quality of the water across wide region, like rivers, lakes, or hydroponics, it is thus required to install a system. According to the state of world today, IoT and distant sensing methods are utilized in a variety of study fields to monitor, collect and analyze data from distant locations. The proposed system-DCWQM includes a wide variety of sensors interfaced to ESP-32 for measuring physical and chemical parameters of drinking water. This method allows analyzing of data that has been posted online through Blynk App and the real-time assessment of water body quality.

Keywords: IoT · water quality · ESP-32 · real time assessment · Blynk app

1 Introduction

All living things require water to survive, and it is not possible to live without it. Environmental pollution has grown to be a big issue as a result of technological development and industrialization. The most significant kind of pollution is water pollution. Our survival depends on the standard of the water we drink in a variety of forms, including juices made by the private sector. Any variation in quality of the water would have a negative impact on human health and disrupt ecological balance among all animals. In India among 1.3 billion population 6% of them does not have access to pure water and 54% of them are facing health issues due to lack of awareness about purifying and consuming the healthy drinking water [1]. Due to increased population most of the smart cities implement water reused system, reducing the dependency on fresh water. SiGeSn/GeSn based inter band multiple quantum well infrared photo detectors can provide better results in designing smart cities [2]. The characteristics of the water's chemical, radiological, and biological composition are referred to as its quality. Depending on how water is used, different important characteristics of the water quality apply. To protect the safety of the fish within an aquarium, for instance, it is required to keep the water's temperature, pH level,

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