Editorial for Special Issue: Underwater Acoustics, Communications, and Information Processing

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1. Introduction

Information and communication technologies (ICT) have brought forth various useful tools and services, enabling another Internet-based industrial revolution over the last few decades. However, oceans or underwater spaces are not enjoying the benefits of the ICT conveniences, mainly due to the complicated underwater physiology and poorly propagating electromagnetics. Subsequently, underwater acoustics and medium channels have been widely investigated, including the limited bandwidth, extended multipath, and refractive properties of the medium, severe fading, rapid time-variation, and large Doppler shifts [1]. Further information processing and communication techniques over the underwater acoustic channel are under successful adopting and upgrading towards practical ocean tools, from the ones originally developed for terrestrial channels [2,3]. Conclusively, we may expect that the underwater acoustics discipline benefits in parallel with the development of the typical ICT discipline, in the sense of digitalization, wireless development, various signal processing hardware and software, and information processing capabilities.

Underwater acoustics for oceanology comprises a well-defined scientific area physically and theoretically for underwater information and communications, whereas digital communication engineering complements practical devices, systems, and networks for interdisciplinary underwater communications [2,3]. Fully utilizing emerging and state-of-the-art tools from both underwater acoustic sciences and communication engineering, we are expecting a quantum jump in various development and interdisciplinary underwater engineering accomplishments covering, for example, shallow water channel characterization, high-speed underwater communication systems, underwater physiological property monitoring, underwater surveillance networks, and many more applications for daily ocean life equipped with the Internet of Things.

This Special Issue aimed at providing the underwater acoustics community with scientific tools, novel information processing algorithms and methods, and underwater applications of acoustics in oceanology. Moreover, various research areas may be found in the underwater acoustics domain, including techniques such as digitalization, wireless development, various signal processing hardware and software, and information processing capabilities. Manuscripts were solicited to address a wide range of topics on the principles and applications of underwater acoustics, including, but not limited to, the following:

- Underwater channel modeling and data processing
- Robust detection and estimation against underwater channels
- High-speed underwater communication systems and networks
- Underwater and ocean physiological property monitoring
- Robust ranging and localization against underwater channels
- Underwater tracking and surveillance networks
- Underwater acoustics in ocean and coastal applications

Approximately three dozen submissions were received in total, from which we selected 16 papers for publication in this issue. These selections are interdisciplinary engineering results of ICT and underwater acoustics, for presenting innovative and new developments quite relevant for the scope of this Special Issue as specified in the following keywords: (1) Underwater Channel Characterization, (2) Underwater Acoustic Communication Systems, and (3) Underwater Target Detection and Localization.

2. Underwater Channel Characterization

To design a conventional communication system, the standard approach is to understand the transmission medium and characterize the channel with a proper model. The communication system design is to optimize an objective function for an efficient transmission over the channel model. Historically, the channel model for basic terrestrial communications was rather simple, such as a randomly homogeneous one (e.g., the additive white Gaussian) or the fading amplitude one represented as a multiplicative model, either in the signal domain or in the log-scale power domain [2]. However, the basic underwater medium is expressed rather as a complex time-varying, temperature- and depth-dependent one and more properly expressed as a kind of multi-layer heterogeneous model [3], which makes underwater system optimization difficult. In other words, underwater channel characterization is more important for the underwater communication system design and implementation, especially considering various unique environmental effects of the specific sites for the system deployment. It is noteworthy that a coastal area becomes more complex because of a boundary problem, whereas open ocean problems neglect geological boundary conditions. Subsequently, the channel characterization of underwater acoustics is still interesting, both experimentally and analytically.

To obtain a realistic perspective on a coastal sea channel near Vladivostok, Morgunov et al. performed an experimental study in [4] in the shallow sea area, to understand the special aspects of scalar-vector sound field spatial structures as the first step of underwater channel characterization. They towed a low-frequency acoustic source on the continental shelf of the Sea of Japan, with the source emitting a 134 Hz acoustic signal, at a depth of 20 m at distances of up to 10 km from the combined receiver. The main results include the possibility of a practical application of the quantitative characteristics and features of the formation of signal interference at several depths along the tracks. It is interesting to note that, from the results of comparing horizontal and vertical field components, it follows that it is possible to identify the presence of vortex structures in the acoustic source field on several tracks.

Further in [5], "Variability of Hydroacoustic Noise Probability Density Function at the Output of Automatic Gain Control System", Gorovoy et al. characterized the underwater channel noise through experiments. These resulted in the estimation of temporal variability of the underwater acoustic noise probability density function (PDF) in shallow waters within the frequency band of 0.03–3.3 kHz, along the Primorsky Aquarium on Russky Island, Vladivostok, Russia. The comparative results show a white Gaussian noise with respect to the sea noise PDF estimates in the same frequency range.

Kim et al. numerically investigated the effects of viscous flux vectors on hydrofoil cavitation flow, dynamically to characterize and model the radiated flow noise in [6], to resolve computational complexity and numerical instability problems. Their work justified the conclusion that the thin-layer

model could provide predictions as accurate as the full viscous model, but required less computational time. They examined the effects of the viscous flux vectors on the predicted flow fields and its radiated noise. Additionally, the hydro-dynamic forces, velocity distribution, volume fraction, far-field sound directivities, and sound spectrum of the three approaches were compared.

To develop a practical channel model through analysis, applicable to realistic ocean applications, Zhang et al. estimated doubly spread acoustic channels based on wavelet transform (WT) in [7]. Typically, a simple model represents underwater acoustic channels, usually with severe delay spread and significant Doppler effects. In contrast with the orthogonal matching pursuit (OMP) algorithm searching in both the time domain and the Doppler domain, the proposed WT-based algorithm only searches in the time domain by using the Doppler invariant characteristic of hyperbolic frequency modulation signal. Extensive simulations showed that the WT-based algorithm performs slightly better than the conventional OMP algorithm, especially in the small signal-to-noise ratio, while using less computational complexity.

3. Underwater Acoustic Communication Systems

After proper channel characterization, system engineers perform waveform design, modulation selection, further signal shaping against channel, and proper receiver implementation, mainly physically, for the communication system configuration.

Rodionov et al. proposed the constant envelope frequency-modulated orthogonal frequency division multiplexing (FM-OFDM) for underwater acoustic communication systems in [8], and justified experimentally that the system works well in a channel, less than 25 km long, with strong impulse noises and quasi-non-stationary properties.

In [9], "Chaos-Based Underwater Communication with Arbitrary Transducers and Bandwidth", Bai et al. used a chaotic communication system with an enhanced differential chaos shift keying (DCSK) for underwater acoustic communications. Among various forms of DCSK, such as correlation delay shift keying (CDSK), phase-separated DCSK (PS-DCSK), high-efficiency DCSK (HE-DCSK), and reference-modulated DCSK (RM-DCSK), the new proposal based on a first-order hybrid chaotic system showed the best performance.

Time-reversal processes represent a scheme to generate a spatio-temporal focus at a source location by transmitting a time-reversed version of a received signal, reducing inter-symbol interference at the receiver, and improving communication performance, in the harsh environment characterized by significant multipath channels. Time-reversal beamforming is a well-known approach in practice, and Kim et al. proposed in [10] a passive time-reversal communication system for shallow water applications. Specifically, they introduced a new measure Eq of an estimate of how much of the q-function lies within one symbol duration, where the q-function is estimated by a sum of the autocorrelation of the channel impulse response for each channel in the receiver array. As a result, the parameter Eq shows a strong correlation to the bit error rate and the output signal-to-noise ratio obtained after the time-reversal operation.

Furthermore, in [11], "Virtual Source Array-Based Multiple Time-Reversal Focusing", Byun et al. investigated time-reversal beamforming using virtual sources. For the time reversal to focus correctly, the focusing requires the source for a coherent acoustic focus at its origin, whose requirement is known to be partially relaxed by the introduction of the concept of a virtual source array (VSA). They extended the existing VSA-based single focusing to simultaneous multiple focusing, by resolving the multiple constraint problem derived from a constraint matrix, with appropriately synchronized transfer functions. Through numerical simulations, they showed that simultaneous multiple focusing guarantees a distortionless response at selected multiple locations, yet its performance degrades according to the presence of sound speed mismatch. To further achieve robust multiple focusing in the mismatched sound speed environment, a singular value decomposition algorithm is applied to find the weight backpropagation vector, approximating the column vectors of the constraint matrix [11].

Baek et al. in [12], "Study on the Structure of an Efficient Receiver for Covert Underwater Communication Using Direct Sequence Spread Spectrum", considered a special purpose communication system under a hostile underwater environment. Spread spectrum techniques are known to provide a low probability of interception property, and turbo equalization techniques employing a RAKE receiver and a decoding with repetition are employed additionally, to improve system performance even at a low signal-to-noise ratio due to the spread spectrum technique.

In [13], "A Novel Fractional Fourier Transform-Based ASK-OFDM System for Underwater Acoustic Communications", Ashri et al. proposed an alternative underwater system using fractional Fourier transform. The proposed fractional Fourier transform-based orthogonal frequency division multiplexing (FrFT-OFDM) system employs the amplitude shift keying (ASK) modulation technique (hence, the name FrFT-ASK-OFDM). Specifically, ASK achieves a good bandwidth efficiency, and the data rate of the proposed system is approximately double the values of the corresponding conventional OFDM systems with the same resource parameters.

Once the hardware or physical system configurations are fixed, upper layers or resource management issues remain, which include an efficient and fair medium access, scheduling of resource management, cognitive management of communication resources, etc. [14–16].

In [14], "Message Collision Avoidance Protocols for Detecting Stray Nodes in a Scuba Diving Group Using Ultrasonic Multi-Hop Message Communication", Kaido et al. investigated the medium access for recreational scuba divers not to make critical message collision during slow underwater acoustic communications. The proposed protocol, over an ad hoc mesh network between divers to detect a stray diver, suggests that messages are relayed in multiple hops with a message collision avoidance method, which reduces the packet loss rate caused by message propagation delay. They implemented the proposed methods in a network simulator, and compared them with existing communication methods.

Yun et al. proposed a resource management protocol for the backhaul of underwater cellular networks in [15]. They consider an underwater base station-initiating (UBSI) resource allocation problem, which is a new approach to determine the backhaul capacity of underwater base stations (UBSs), in the sense that a UBS initiates to redetermine its backhaul capacity according to its queue status. The protocol is simulated to be appropriate and efficient to the underwater backhaul link, especially when the transmission rate is quite low and the latency is unneglectable.

In [16], Ghafoor et al. proposed a cognitive routing in software-defined underwater acoustic networks. Cognitive networks presume two different types of primary users, one natural acoustic and the other artificial acoustic, and there is a long propagation delay for acoustic links in underwater cognitive acoustic networks. Thus, the selection of a stable route in the underwater acoustic networks is a key design factor to improve the overall network stability, thereby reducing end-to-end delay. Under the software-defined or software-configurable networking, they proposed a novel routing protocol that two nodes can only communicate when they have a consensus about a common idle channel, to find a stable route between source and destination.

4. Underwater Target Detection and Localization

Once proper communication systems are implemented for harsh underwater environments, there are abundant applications to be extended further towards ocean engineering, such as underwater navigation, underwater exploitation, and underwater monitoring and engineering, for which target detection, ranging, object localization and tracking, and ocean property tomography are some key technologies to be further refined.

In [17], "Target Localization in Underwater Acoustic Sensor Networks Using RSS Measurements", Chang et al. investigated the classical object localization issue but against the harsh underwater environment. This underwater target localization problem presumes received signal strength (RSS) measurements, especially in cases of unknown transmit power condition, and a fast implementation algorithm is proposed by transforming the non-convex problems into a generalized trust region

subproblem framework. The authors used computer simulations to show the superior performance of the proposed methods in the realistic underwater environment.

Underwater multi-object tracking while moving is another interesting problem in active sonar systems. Chen et al. proposed to improve the conventional probability hypothesis density (PHD) and cardinalized PHD (CPHD) algorithms for an active acoustic tracking system in [18]. Particularly when the detection probability is not available as a priori, it is necessary to estimate simultaneously the number of multi-targets, the detection probability, and their states. The detection probability is proposed as "Pd", analytically formulated for a fixed false alarm rate, and adding the adaptive ellipse gate strategy to reduce the computational load in the conventional PHD and the cardinalized PHD CPHD algorithms. Finally, under the linear Gaussian mixture (GM) channel assumption, the proposed Pd-GM-PHD and Pd-GM-CPHD algorithms are more realistic and accurate in underwater active sonar tracking systems.

The issue of detecting objects bottoming on the sea floor is interesting in a practical sense, and Seo et al. proposed an underwater cylindrical object detection algorithm using the spectral features of active acoustic signals in [19]. The main idea in their work was to use the logistic regression model to discriminate the target from the clutter and to train the model using sufficient data in the real world. Once the logistic regression model is trained by the simulated data that are generated based on the mathematical model for the backscattering of the cylindrical object, the results verify that the proposed method is effective under the circumstance with insufficient experimental data, when a mathematical model of the target is available.

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