Editorial

Advances in Signal Processing for Maritime Applications

Frank Ehlers,[1] Warren Fox,[1] Dirk Maiwald,[2] Martin Ulmke,[3] and Gary Wood[4]

[1] NATO Undersea Research Centre (NURC), Viale S. Bartolomeo 400, 19126 La Spezia, Italy
[2] nkt cables GmbH, Schanzenstraße 6-20, 51063 Köln, Germany
[3] Fraunhofer FKIE, Neuenahrer Strasse 20, 53343 Wachtberg, Germany
[4] Naval Systems Department, DSTL Portsdown West, Portsdown Hill Road, Fareham PO17 6AD, UK

Correspondence should be addressed to Frank Ehlers, frankehlers@ieee.org

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1. Introduction

The maritime domain continues to be important for our society. Significant investments continue to be made to increase our knowledge about what "happens" underwater, whether at or near the sea surface, within the water column, or at the seabed. The latest geophysical, archaeological, and oceanographical surveys deliver more accurate global knowledge at increased resolutions. Surveillance applications allow dynamic systems to be accurately characterized. Underwater exploration is fundamentally reliant on the effective processing of sensor signal data.

All maritime applications face the same difficult operating environment: fading channels, rapidly changing environmental conditions, high noise levels at sensors, sparse coverage of the measurement area, limited reliability of communication channels, and the need for robustness and low energy consumption, just to name a few. There are obvious technical similarities in the signal processing that have been applied to different measurement equipment, and this special issue aims to help foster cross-fertilization between these different application areas.

The articles in this special issue cover the following topics: First, underwater acoustics: "*Underwater broadband source localization based on modal filtering and features extraction*", "*Simulation of matched field processing localization based on EMD denoising and Karhunen-Loève expansion in underwater waveguide environment*," "*A relative-localization algorithm using incomplete pair-wise distance measurements for underwater applications*," "*Acoustic particle detection with the ANTARES detector*," "*Masking of time-frequency patterns in applications of passive underwater target detection*," "*An underwater acoustic implementation of DFT-spread OFDM*," "*Low complexity iterative receiver design for shallow water acoustic channels*," and "*Automatic indexing and content analysis of whale recordings and XML representation*."

Second, underwater nonacoustics: "*Silent localization of underwater sensors using magnetometers*", "*Hausdorff-based RC and IESIL combined positioning algorithm for underwater geomagnetic navigation*", and "*Realistic subsurface anomaly discrimination using electromagnetic induction and an SVM classifier*".

Third, radar: "*CFAR detection from non-coherent radar echoes using bayesian theory*", "*Artificial neural network-based clutter reduction systems for ship size estimation in maritime radars.*"

Fourth, optics: "*An evaluation of pixel-based methods for the detection of floating objects on the sea surface*," "*Statistical real-time model for performance prediction of ship detection from micro-satellite electro-optical imagers*," "*Techniques for effective optical noise rejection in amplitude-modulated laser optical radars for underwater three-dimensional imaging*," "*Underwater image processing: state of the art of restoration and image enhancement methods*," and "*A fully automated method to detect and segment a manufactured object in an underwater color image.*"

2. Underwater Acoustics

M. Lopatka et al. address the task of underwater broadband source localization based on modal filtering and features extraction. They focus on shallow water environment and broadband Ultra Low-Frequency acoustic sources. In this

configuration and at a long range the acoustic propagation can be described by normal mode theory. The propagating signal breaks up into a series of depth dependent modes. These modes carry information about the source position. Mode excitation factors and mode phases analysis allow, respectively, localization in depth and distance. The authors propose two different approaches to achieve the localization: multidimensional approach (using a horizontal array of hydrophones) based on frequency-wavenumber transform and monodimensional approach (using a single hydrophone) based on adapted spectral representation. For both approaches they propose first complete tools for modal filtering and then depth and distance estimators. Adding mode sign information improves considerably the localization performance in depth. They show also that an important issue is the source spectrum. They propose a simple method of source spectrum estimation and demonstrate how it can improve depth localization. The reference acoustic field needed for depth localization is simulated with a new realistic propagation model. The feasibility of both approaches is validated on data simulated in shallow water for different configurations. The performance of localization, both in depth and distance, is very satisfactory.

Q. Wang et al. present a simulation of matched field processing (MFP) localization based on Empirical mode decomposition (EMD) denoising and Karhunen-Loève expansion in the underwater waveguide environment. The mismatch problem has been one of important issues of matched field processing for underwater source detection. Experimental use of MFP has shown that robust range and depth localization is difficult to achieve. In many cases this is due to uncertainty in the environmental inputs required by acoustic propagation models. The authors present a combined scheme with EMD denoising and Karhunen-Loève expansion. Results on performance, robustness, and effectiveness of the proposed method are given for simulated data.

K. Y. Foo et al. present a relative-localization algorithm using incomplete pairwise distance measurements for underwater applications. The task of localizing underwater assets involves the relative localization of each unit using only pair-wise distance measurements, usually obtained from time-of-arrival or time-delay-of-arrival measurements. In the fluctuating underwater environment, a complete set of pair-wise distance measurements can often be difficult to acquire, thus hindering a straightforward closed-form solution in deriving the assets' relative coordinates. An iterative multidimensional scaling approach is presented based upon a weighted-majorization algorithm that tolerates missing or inaccurate distance measurements. Substantial modifications are proposed to optimize the algorithm, while the effects of refractive propagation paths are considered. A parametric study of the algorithm based upon simulation results is shown. An acoustic field-trial was then carried out, presenting field measurements to highlight the practical implementation of this algorithm.

C. Richardt et al. present the acoustic particle detection with the ANTARES detector. The AMADEUS (Antares Modules for Acoustic Detection Under the Sea) system within the ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESsearch) neutrino telescope is designed to investigate detection techniques for acoustic signals produced by particle cascades. While passing through a liquid a cascade deposits energy and produces a measurable pressure pulse. This can be used for the detection of neutrinos with energies exceeding 10^{18} eV. The AMADEUS setup consists of 36 hydrophones grouped in six local clusters measuring about one cubic meter each. The article focuses on acoustic particle detection, the hardware of the AMADEUS detector, and techniques used for acoustic signal processing.

J. Sildam investigates the application of masking of time-frequency patterns in applications of passive underwater target detection. Spectrogram analysis of acoustical sounds for underwater target classification is utilized when loud nonstationary interference sources overlap with a signal of interest in time but can be separated in time-frequency (TF) domain. He proposes a signal masking method which in a TF plane combines local statistical and morphological features of the signal of interest. A dissimilarity measure D of adjacent TF cells is used for local estimation of entropy H, followed by estimation of $\Delta H = H_{tc} - H_{fc}$ entropy difference, where H_{fc} is calculated along the time axis at a mean frequency fc, and H_{tc} is calculated along the frequency axis at a mean time tc of the TF window, respectively. Due to a limited number of points used in ΔH estimation, the number of possible ΔH values, which define a primary mask, is also limited. A secondary mask is defined using morphological operators applied to, for example, H and ΔH. He demonstrates how primary and secondary masks can be used for signal detection and discrimination, respectively. He also shows that the proposed approach can be generalized within the framework of Genetic Programming.

Y. Zhang et al. discuss the implementation of DFT-spread OFDM for underwater acoustics. The paper presents a design of DFT-spread OFDM system applied to an underwater acoustic channel. It not only combines all the advantages of a conventional OFDM system but also reduces the peak-to-average power ratio of the transmit signal. Besides, the scheme spreads the information over several subcarriers as a result of the application of an additional DFT operation and leads to a diversity gain in a frequency-selective fading channel, which is one of the many challenges of communicating data through an underwater acoustic channel. Simulation results show that their proposal possess good bit-error-rate performance. The system has been tested in a real underwater acoustic channel—the experimental pool in Xiamen University. The experimental results show that the DFT-spread OFDM system can achieve better results than a simple OFDM system in a benign underwater channel.

C. P. Shah et al. present a low complexity iterative receiver design for shallow water acoustic channels. An adaptive iterative receiver structure for the shallow underwater acoustic channel (UAC) is proposed using a decision feedback equalizer (DFE) and employing bit interleaved coded modulation with iterative decoding (BICM-ID) in conjunction with adaptive Doppler compensation. Experimental results obtained from a sea trial demonstrate that

the proposed receiver not only reduces the inherent problem of error propagation in the DFE but also improves its convergence, carrier phase tracking, and Doppler estimation. Furthermore, simulation results are carried out on UAC, modelled by utilizing geometrical modelling of the water column that exhibits Rician statistics and a long multipath spread resulting in severe frequency selective fading and intersymbol interference (ISI). It has been demonstrated that there is a practical limit on the number of feedback taps that can be employed in the DFE and data recovery is possible even in cases where the channel impulse response (CIR) is longer than the span of the DFE. The performance of the proposed receiver is approximately within 1 dB when compared with the performance of the system employing DFE-turbo-BICM, however, at much lower computational complexity and memory requirements, features that are attractive for real-time implementation.

F. Bénard et al. address the task of automatically indexing and analyzing whale recordings leading to an XML representation. The paper focuses on the robust indexing of sperm whale hydrophone recordings based on a set of features extracted from a real-time passive underwater acoustic tracking algorithm for multiple vocalizing whales using four or more omnidirectional widely spaced bottom mounted hydrophones. In past years, interest in marine mammals has increased leading to the development of robust and real-time systems. Acoustic localization permits the study of whale behavior in deep water (several hundreds of meters) without interfering with the environment. The authors recall and use a real-time multiple target tracking algorithm recently developed, which localizes one or more sperm whales. Given the position coordinates, they are able to generate different features such as the speed, energy of the clicks, and Interclick-Interval (ICI). These features allow the authors to construct different markers which allow them to index and structure the audio files. Thus, the behavior study is facilitated by choosing and accessing the corresponding index in the audio file. The complete indexing algorithm is processed on real data from the NUWC1 and the AUTEC2. Their model is validated by similar results from the US Navy3 and SOEST4 Hawaii university labs in a single whale case. Finally, as an illustration, they index a single whale sound file using the extracted whale's features provided by the tracking, and they present an example of an XML script structuring it.

3. Underwater Nonacoustics

J. Callmer et al. present a silent localization procedure for underwater sensors using magnetometers. Sensor localization is a central problem for sensor networks. If the sensor positions are uncertain, the target tracking ability of the sensor network is reduced. Sensor localization in underwater environments is traditionally addressed using acoustic range measurements involving known anchor or surface nodes. They explore the usage of triaxial magnetometers and a friendly vessel with known magnetic dipole to silently localize the sensors. The ferromagnetic field created by the dipole is measured by the magnetometers and is used to localize the sensors. The trajectory of the vessel and the sensor positions are estimated simultaneously using an Extended Kalman Filter (EKF). Simulations show that the sensors can be accurately positioned using magnetometers.

L. Yi presents a primitive solution with novel scheme and algorithm for Underwater Geo-magnetic Navigation (UMN), which now occurs as the hot-point in the research field of navigation. UMN as an independent or supplementary technique can theoretically supply accurate locations for marine vehicles, but in practice there are plenty of restrictions for UMN's application (e.g., geomagnetic daily variation). After analysis about the theoretical model of geomagnetic positioning in the correlation-matching mode from the viewpoint of pattern recognition, the author proposes an appropriate matching scenario and a combined positioning algorithm for UMN. The subalgorithm of Hausdorff-based Relative Correlation (RC) corresponding to the pattern classification module implements the coarse positioning, and the subalgorithm of Isograms Equidistance-Segmenting the Intersection Lines (IESILs) associated with the module of feature extraction continues the fine positioning. The experiments based on the simulation platform and the real-surveyed data both validate the new algorithm, and its efficiency and accuracy are also discussed. It can be concluded that the work introduced in the paper gives an initial and real validation of UMN's potentiality.

J. P. Fernández et al. investigate realistic subsurface anomaly discrimination by using electromagnetic induction and an SVM classifier. The environmental research program of the United States military has set up blind tests for detection and discrimination of unexploded ordnance. One such test features data collected with the EM-63 sensor at Camp Sibert, AL. They review the performance on the test of a procedure that combines a field-potential (HAP) method to locate targets, the normalized surface magnetic source (NSMS) model to characterize them, and a support vector machine (SVM) to classify them. The HAP method infers location from the scattered magnetic field and its associated scalar potential, the latter reconstructed using equivalent sources. NSMS replaces the target with an enclosing spheroid of equivalent radial magnetization whose integral it uses as a discriminator. SVM generalizes from empirical evidence and can be adapted for multi-class discrimination using a voting system. The proposed method identifies all potentially dangerous targets correctly and has a false-alarm rate of about 5%.

4. Radar

H. Yamaguchi et al. propose a new constant false alarm rate (CFAR) detection method from noncoherent radar echoes, considering heterogeneous sea clutter. It applies the Bayesian theory for adaptive estimation of the local clutter statistical distribution in the cell under test. The detection technique can be readily implemented in existing noncoherent marine radar systems, which makes it particularly attractive for economical CFAR detection systems. Monte Carlo simulations were used to investigate the detection performance and

demonstrated that the proposed technique provides a higher probability of detection than conventional techniques, such as cell averaging CFAR (CA-CFAR), especially with a small number of reference cells.

R. Vicen-Bueno et al. present artificial neural network-based clutter reduction systems for ship size estimation in maritime radars. The existence of clutter in maritime radars deteriorates the estimation of some physical parameters of the objects detected over the sea surface. For that reason, maritime radars should incorporate efficient clutter reduction techniques. Due to the intrinsic nonlinear dynamic of sea clutter, nonlinear signal processing is needed, what can be achieved by artificial neural networks (ANNs). In the paper, an estimation of the ship size using an ANN-based clutter reduction system followed by a fixed threshold is proposed. High clutter reduction rates are achieved using 1-dimensional (horizontal or vertical) integration modes, although inaccurate ship width estimations are achieved. These estimations are improved using a 2-dimensional (rhombus) integration mode. The proposed system is compared with a CA-CFAR system, denoting a great performance improvement and a great robustness against changes in sea clutter conditions and ship parameters, independently of the direction of movement of the ocean waves and ships.

5. Optics

A. Borghgraef et al. discuss the evaluation of pixel-based methods for the detection of floating objects on the sea surface. Ship-based automatic detection of small floating objects on an agitated sea surface remains a hard problem. Their main concern is the detection of floating mines, which proved a real threat to shipping in confined waterways during the first Gulf War, but applications include salvaging, search-and-rescue, and perimeter or harbour defense. Detection in infrared (IR) is challenging because a rough sea is seen as a dynamic background of moving objects with size order shape and temperature similar to those of the floating mine. They have applied a selection of background subtraction algorithms to the problem, and they show that recent algorithms such as ViBe and behaviour subtraction, which take into account spatial and temporal correlations within the dynamic scene, significantly outperform the more conventional parametric techniques, with only little prior assumptions about the physical properties of the scene.

F. D. Lapierre et al. present a statistical real-time model for performance prediction of ship detection from microsatellite electro-optical imagers. For locating maritime vessels longer than 45 meters, such vessels are required to set up an Automatic Identification System (AIS) used by vessel traffic services. However, when a boat is shutting down its AIS, there are no means to detect it in open sea. They use Electro-Optical (EO) imagers for noncooperative vessel detection when the AIS is not operational. As compared to radar sensors, EO sensors have lower cost, lower payload, and better computational processing load. EO sensors are mounted on LEO microsatellites. They propose a real-time statistical methodology to estimate sensor Receiver

Operating Characteristic (ROC) curves. It does not require the computation of the entire image received at the sensor. The authors then illustrate the use of this methodology to design a simple simulator that can help sensor manufacturers in optimizing the design of EO sensors for maritime applications.

R. Ricci et al. apply techniques for effective optical noise rejection in amplitude-modulated laser optical radars for underwater three-dimensional imaging. Amplitude-modulated (AM) laser imaging is a promising technology for the production of accurate three-dimensional (3D) images of submerged scenes. The main challenge is that radiation scattered off water gives rise to a disturbing signal (optical noise) that degrades more and more the quality of 3D images for increasing turbidity. The authors summarize a series of theoretical findings that provide valuable hints for the development of experimental methods enabling a partial rejection of optical noise in underwater imaging systems. In order to assess the effectiveness of these methods, which range from modulation/demodulation to polarimetry, they carried out a series of experiments by using the laboratory prototype of an AM 3D imager ($\lambda = 405$ nm) for marine archaeology surveys, in course of realization at the ENEA Artificial Vision Laboratory (Frascati, Rome). The obtained results confirm the validity of the proposed methods for optical noise rejection.

R. Schettini et al. discuss the state of the art of restoration and image enhancement methods for underwater images. The underwater image processing area has received considerable attention within the last decades, showing important achievements. They review some of the most recent methods that have been specifically developed for the underwater environment. These techniques are capable of extending the range of underwater imaging, improving image contrast and resolution. After considering the basic physics of the light propagation in the water medium, the authors focus on the different algorithms available in the literature. The conditions for which each of them has been originally developed are highlighted as well as the quality assessment methods used to evaluate their performance.

C. Barat et al. present a fully automated method to detect and segment a manufactured object in an underwater color image. They propose a fully automated and active contours-based method for the detection and the segmentation of a moored manufactured object in an underwater image. Detection of objects in underwater images is difficult due to the variable lighting conditions and shadows on the object. The proposed technique is based on the information contained in the color maps and uses the visual attention method, combined with a statistical approach for the detection and an active contour for the segmentation of the object to overcome the above problems. In the classical active contour method the region descriptor is fixed and the convergence of the method depends on the initialization. With their approach, this dependence is overcome with an initialization using the visual attention results and a criterion to select the best region descriptor. The approach improves the convergence and the processing time while providing the advantages of a fully automated method.

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