



Opinion

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# A New Research Direction: Underwater Acoustic Signal Combined Processing Based on Multi-Field Coherence



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## Abstract

The 21<sup>st</sup> century is considered the century of the ocean. There are many acoustic field effects distributed in ocean, including convergence zones, shadow zones, underwater acoustic channels and so on. Regarding the application of underwater acoustic networks, we point out that underwater acoustic signal combined processing based on multi-field coherence is a new research direction, then put forward scientific problems and research approaches for it. We hope that our opinion will guide more researchers to address the topic in order to jointly promote research in this field and obtain more valuable research results.

**Keywords:** Acoustic Multi-Field Effects; Coherence; Signal Combined Processing; Research Direction

## Introduction

The low-cost and highly-reliable underwater acoustic network is an effective means of monitoring the marine environment, detecting seabed resources, searching in marine rescue operations, etc. [1,2]. There are many acoustic field effects distributed in the Pacific, Atlantic, Indian Ocean, etc., including convergence zones, shadow zones, deep sea acoustic channels and so on. The different sensor nodes of the network may be deployed in different acoustic field zones while adopting suitable working modes; for example, sensor nodes deployed in convergence zones adopt the “convergence zone working mode”, while those deployed in the deep-sea acoustic channels adopt the “deep sea acoustic waveguide working mode”. With the increase in the bandwidth and rate of underwater communication, it has become possible to carry out the combined processing of the acoustic signals of distributed nodes. Therefore, achieving processing gain of multi-field coherence and correlation through combined processing of different sensor node signals will become a new research direction.

## Key Scientific Problems for Signal Combined Processing Based on Multi-Field Coherence

It is well known that the time, spatial and frequency coherence properties and laws of acoustic effects form the foundation of signal processing. Many factors such as random fluctuations

on sea surfaces, seabed unevenness, water body heterogeneity, uncertainty of ocean currents, temperature changeability and salinity changeability exist in different acoustic fields, which consequently result in significant differences in their time, spatial and frequency coherence properties. For example, the frequency interference structure, space and time correlation in convergence zones are significantly different from those in the shadow zones. To this end, how to scientifically and rationally hold on the time, spatial and frequency coherence properties and laws among multi-fields, how to carry out the single combined processing between different underwater acoustic network nodes which were deployed in different acoustic fields to achieve high gain is the scientific problem and should to be solved. For example, when the acoustic signals of a shadow zone and those of a convergence zone are processed together, it is necessary to determine whether any interference exists among them or through compensate and modified the phase and amplitude of the signal in order to observe the interference phenomenon.

## Research Approach

The interference phenomenon is a unique characteristic of fluctuation. The coherence of an acoustic field manifests as the interference phenomenon of signal in the spatial, time and frequency. Great achievements have been made in research on

the single acoustic field coherence effects. In 1982, S. D. Chuprova of Moscow State University [3], put forward the innovative and significant "Waveguide Invariant Theory". He first used the normal mode theory and ray acoustic theory to research the mechanism and depiction of interference fringe on the distance-frequency plane. He then pointed out that space-frequency interference fringes are formed by a group of normal mode model coherences with similar orders, and the slope is a scalar value  $\beta$  that does not change with changes in the frequency or mode order number. He called value  $\beta$  the "waveguide invariant" and demonstrated that the waveguide invariant describes the micro-structure characteristics of sound waves propagating in the ocean from a brand-new angle. At present, research on single acoustic field interference structures is gradually shifting from the macroscopic energy to the fine micro-structure [4,5], and from the scalar sound pressure interference structure to the vector interference structure [6]. However, at present, no research has been conducted on the coherence properties and laws among different acoustics fields, and the signals combined processing of multi-field has not yet been achieved [7]. To implement signal combined processing based on multi-field coherence and obtain significant performance gain based on multi-fields effects with wide coverage of different sensor nodes in underwater acoustic network [8].

The following research directions should be explored:

A. Research should be conducted on the spatial correlations among different acoustic fields in typical environments [9,10]. Regarding the different acoustic field effects of convergence zones, deep sea acoustic channels, surface acoustic channels, shadow zones, etc., analyses should be carried out of the different acoustic field levels and vertical correlations, and such relationships among relevant acoustic parameters as sound velocity and spatial distance [11,12]. Theoretical models should be constructed according to the spatial correlations among different acoustic fields, the internal relations and change laws of the spatial correlations of multi-fields should be identified and signals combined processing gain of different nodes should be further analyzed [13,14].

B. Research should be conducted on the time, spatial and frequency interference structures among typical different acoustics fields [15]. Analyses should be carried out of the mechanisms of factors such as seabed terrain, underwater sound velocity distribution, etc. impact on the time, spatial and frequency interference structures among different acoustics fields, and research should be conducted on stable interference structures produced among different acoustics fields and the physical mechanisms that cause interference structures to change [16]. The distribution and robustness of interference structures under the coupling of different acoustics field should be analyzed, and the characteristics and laws models of time, spatial and frequency interference structures of multi-fields should be identified [17].

C. Research should be conducted on the relationship of physical characteristic parameters of the time, spatial and frequency interference structures among typical different acoustics fields [18]. Analyses should be made of the mechanisms of the time, spatial and frequency interference structure formation of multi-fields. Processing methods for improving the stability and tolerance of interference structures should be researched, and the physical characteristic parameters (such as waveguide invariants) of spatial and frequency interference structures among different acoustics fields and their representation models should be put forward [19].

D. Research should be conducted on the combined processing methods of the underwater acoustic signals of multi-fields, and relevant experiments should be carried out [20]. Sound sources and fixedly placed horizontal linear arrays and vertical linear arrays of sensor nodes should be used to carry out experiment in typical ocean environments, and the laws of the spatial and frequency interference structures of multi-fields verified, as well as the spatial correlation laws of multi-fields [21].

### Conclusion

The 21<sup>st</sup> century is considered the century of the ocean. Marine environmental monitoring, marine resource utilization, marine fishery and aquaculture have become important economic pillars in global economic development. Therefore, underwater acoustic signal combined processing based on multi-field coherence achieving much processing gain is a new research direction. We hope that the scientific problems and approaches for the research direction proposed in this paper will guide more researchers to address the topic in order to jointly promote research in this field and obtain more valuable research results in the future.

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