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Scientific potential of a new 3D multibeam echosounder in fisheries and ecosystem research

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ABSTRACT

SEAPIX is a new multibeam echosounder (MBES) with an original architecture using a steerable symmetric Mills Cross. This configuration allows to image water column and sea bottom in both athwartship and fore-and-aft direction. Furthermore, steering capability in transmit and receive allows a volume coverage of 120° × 120° under ship with 1.6° × 1.6° beam aperture on the antenna axis. 64 beams are acquired per ping in the frequency range of 145–155 kHz using monochromatic or frequency modulated burst. Transmitted beams are stabilized in roll or pitch according with the transmitted mode and receiving beams are motion compensated using an embedded inertial motion unit. This MBES has been designed to be installed on fishing vessel and to help fishing strategies as long as to provide useable data for fish scientist. First part of this paper describes hardware main characteristics of the SEAPIX. We then describe signal processing and functionalities of SEAPIX. Finally, we illustrate first sea results on typical case.

1. Introduction

Acoustic systems have been identified among the most promising tools available to scientists for the Ecosystem Approach for Fishery (EAF) (Koslow, 2009). Indeed, these systems have the potential to fulfill many of the needs identified for the discipline as the characterization and identification of targets in the water column or benthic habitat mapping.

On the one hand, in fishery acoustics, acoustic techniques are well known and used daily for biomass assessment by fisheries scientists through echointegration and target strength measurement of isolated fish with split-beam like vertical single beam echosounders calibrated by standardized methods (Foote et al., 1987; Simmonds and MacLennan, 2008).

On the other hand, in hydrography, underwater acoustics is now used routinely through high performance bathymetric multibeam echosounder (MBES) to establish standardized navigation maps (Debese, 2013).

Moreover, most of MBES and sidescan sonars measure the backscattering coefficient of the bottom. Forward model and inversion methods allow characterization and classification of sea bottom (Anderson, 2007) and provide the opportunity to establish thematic maps of the seafloor. Much work is underway on the subject including the standardization of methods of measurement, calibration and classification, as evidenced for example the work of GEOHAB group (Harris and Baker, 2011). MBES also perform seagrass identification and characterization (Komatsu et al., 2003) which can be a key parameter for ecosystem management.

More recently, MBES has been used to analyze the water column, including backscattering measurement, single echo detection and volume imaging of schools of fish (Colbo et al., 2014). First pioneering work consisted in a qualitative display of the water column using standard hydrographic MBES (Gerlotto et al., 1999). Then, specific innovation in MBES data display for fishery research took benefit from the increasing 3D graphic display capabilities (Mayer et al., 2002). These new 3D visualization tools have created a real gap in the way of understanding the water column data. Finally the acoustic calibration methods have been adapted for the MBES allowing quantitative exploitation of data from the water column (Foote, 2006).

MBES have considerable advantages over conventional fishery single beam echosounder (SBES). First, they offer a much larger volume coverage, which corresponds to 120–150° athwartship aperture for MBES versus 7–12° for standard split-beam SBES. Then, it permits a fine positioning of fish detection athwartship thanks to a small angular beam width, basically from 0.5° to 2°. Finally small beam aperture and secondary lobe reduction allows fish detection close to the bottom.

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Following those pioneering works, Simrad and Ifremer developed a MBES designed specifically for fishery applications, the ME70 (Trenkel et al., 2008). This system is made of a two dimension transducer array and can deal with 45 beams in transmit and receive simultaneously. This design is very efficient for secondary lobe reduction that can be down to −70 dB. These features make it a tool extremely efficient for near bottom biomass analysis as well as study of small pelagic fish (Trenkel et al., 2009). Furthermore, its large bandwidth (70–120 kHz) makes it suitable for multi-frequency analysis. New capabilities of this tool are exploited using dedicated software, like MOVIES 3D developed by IFREMER (Trenkel et al., 2009), or the 3D Module of Echoview (Buelens et al., 2003), that includes simultaneous 3D display, bottom detection and school analysis.

The use of these systems opens new opportunities for research. For instance, three-dimensional analysis of geometric parameters of school that deepens the methods of geometry-based school identification already in place for single beam echo sounders (Scalabrin et al., 1996). Those morphological indicators can be height, width, or elongation of the school, the volume backscattering coefficient, or more recently the internal density structure of the school as the rate of vacuoles (Gerlotto and Paramo, 2003; Guillard et al., 2011). Improvement in volume coverage and angular and range resolution drastically increase the number of individual echoes in comparison with standard SBES. This larger number of detection allows considering statistical analysis of fish echoes, that can provide new insight on fish shoal, like density or multi-species composition (Stanton and Clay, 1986; Frouzova et al., 2011).

All these features for water column and bottom analysis, coupled with database construction referenced in space and time, are intended to define the characteristics of the habitat of fish (Schimel et al., 2010; Brown et al., 2011).

In the meantime, an increasing number of scientific works are based on opportunity data collected by Fishery industry (Melvin et al., 2002; Bertrand et al., 2005). The availability of calibrated echosounders on fishing vessels appears to be a growing need, allowing both to offer more comprehensive information to the crew about the fishing environment and producing a workable dataset for fisheries scientific community.

To summarize the current scientific need would be filled by an instrument capable of:

– detecting and characterizing objects in the water column in a large volume under the vessel, with calibrated repeatable and reproducible data of scattering cross-section for point, surface and volume target (TS, BS and SV),
– measuring bathymetry and characterizing the seabed,
– getting georeferenced data in real-time and standardized.

In parallel of those developments in Fisheries Research, the fishing activity is subject to new constraints that arose recently and directly affecting the fleet productivity. Among them, there may be mentioned:

- Fuel costs: Despite recent declines, the cost of oil remains the main cost item of fishing vessel. Fishermen therefore need to acquire more information allowing them to optimize their fishing route. In particular, a better understanding of the bottom (bathymetry and type) and the position of the fishing vessel and gear relative to the school spotted.
- New regulations: Regulatory developments about discards, imposing the fishermen to have a better knowledge about the species and size of individuals caught. These new regulations raise the cost of by-catch (fine, quota reduction) in addition of the cost of the fishing operation.
- Operation safety: Those new economical constraints encourage fishermen to explore new fishing zones. These practices increase the risk for trawler to hook on the unexplored seabed.

In this context emerged the need of new sensors for fishermen enabling them both to optimize their fishing operation and improve their fishing selectivity. SBES do not provide these types of information, and MBES becomes one of the few systems usable for such objective, mainly because of the volume reconstruction of the fishing zone. Indeed, as mentioned previously, MBES can provide fishermen information about bathymetry, bottom type and school cross-section simultaneously and in real-time. From that information, among others, fishermen may deduce benthic habitat or fish species and ultimately optimize his fishing operation with respect of efficiency and selectivity.

In conventional MBES, the volume reconstruction is done through the trajectory of the vessel (2D + time). Several issues of fisheries operations such as school avoidance, hook detection or bottom lift, highlights the need for a truly 3D MBES covering a wide volume under the vessel without moving.

To address this need, iXBLue began in 2010 to develop a new type of 3D MBES based on steerable symmetrical Mills Cross, in order to offer a good tradeoff between hardware cost and versatility of the system. The original architecture of SEAPIX makes it possible to analyze the water column and bottom in transverse section as in conventional MBES but also to steer this sections in the fore or aft direction of the vessel or reverse the transmitting and receiving antennas so as to image longitudinal section steerable to port or starboard. SEAPIX makes it possible to cover a wide volume under the vessel without any vessel displacement, within the echosounder range which will be further discussed.

Today SEAPIX equips more than thirty fishing vessels and is used routinely by fishermen in pelagic and benthic context. Our recent work tends to ensure that those data can be used by fishery scientist, arising questions like: calibration (in-tank and in-situ), repeatability and reproducibility of measurement, data compatibility with third-part equipment or data standardization. In the following we will describe the technical characteristics of SEAPIX hardware, detailed signal processing and functionalities offered and calibration modalities of the system. Finally, we present the first results obtained with this system in both pelagic and benthic applications.

2. Characteristics of the SEAPIX 3D MBES

SEAPIX is a 3D MBES using a steerable symmetrical Mills Cross (Urick, 1983). This is to say that each of the two antennas may operate in both transmit and receive and are steerable. Each antenna is composed of 64 elements spaced of the half of the wavelength with the exception of the central transducers. The system works on a band of 10 kHz around 150 kHz. For every ping, the MBES forms 64 beams equi-angularly distributed between −60° and +60° about the axis of the antenna. The angular aperture beam varies from 1.6° for central beams to 3.2° for extreme beams. At the beamforming stage it is possible to apodize sensors. Whether apodization is applied, sidelobes levels rejection can be 13–20 dB. Sidelobes reduction provokes a slight widening of the beam, which does not exceed 2° for the central beam.

SEAPIX transmits monochromatic or linearly frequency modulated pulses of length from 100 μs to 20 ms. Maximum duty cycle of the system is 20% and maximum range is 600 m. Digitized signal is coded on 12 bits and time varying gain dynamic is 57 dB. The overall dynamic of the system is 123 dB. In the current version, source level is 206 dB (re.1 μPa at 1 m) and a prototype of future version is currently under test with source level of 213 dB (re.1 μPa