SeapiX : an innovative multibeam multiswath echosounder for water column and seabed analysis

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Abstract - **Seapix is a reversible Mills Cross multibeam echosounder composed of two arrays, each of them stabilizing beams with a mems sensor included in the Sonar head. This multi-beam SONAR provide metrological target strength (TS) and volume backscattering strength (SV) on multiple swathes. Among others environmental variables, indicators like TS or SV are exploited for fish discrimination. Each detection is referenced in 3D in the water column and is automatically reported on a map built in real time including local bathymetry. According to IHO standards, Seapix bathymetry is special order when coupled with external high quality motion reference unit. Additionally, a robust seabed classification method using the multiswath capability of the echosounder will be presented. Classification rate up to nearly 100 % on have been obtained on a reference dataset with sparse posidonia, dense posidonia, and sand. In static conditions, Seapix is also able to construct a bathymetry by steering beams over a region of interest in very turbid conditions as encountered in dredging or dragging. Acquisitions have been performed on 10 m depth, reaching a coverage of 27 x 30 m under the barge.**

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, electronic steering capability in transmit and receive allows a volume coverage of 120°x120° under ship with 1.6°x1.6° beam aperture on the antenna axis. 64 beams are acquired per ping in the frequency range of 145-155kHz using monochromatic or frequency modulated burst. More precisely 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, side lobes levels goes from -13dB to -20dB, which provokes a slight widening of the beam, which does not exceed 2° for the central beam. 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. Transmitted pulses are either monochromatic or linearly frequency modulated pulses of length from 100µs to 20ms. Maximum duty cycle of the system is 20% and bottom was experimentally detected down to 845 m. Digitized signal is coded on 12 bits and time varying gain dynamic is 57dB. The overall dynamic of the system is 123dB. In the current version, source level is 216dB (re.1µPa at 1m). Self-noise of the system at 150 kHz is 22dB (re.1µPa/$\sqrt{}$Hz) and corresponds to the Johnson noise of the sensors. At the receiving stage, each antenna is split in two halves and 64 beams are formed with each sub-antenna. Those sub-antenna beams are used in two manners. First, beams are summed in amplitude to form full resolution beams. Secondly, an interferometric processing consisting in calculating the phase difference between same angle beams is computed. Amplitude signal is used for bathymetric detection in the near-axis direction. Phase signal is used for bathymetric detection for large grazing angle (>20° relatively to MBES axis) or for split-beam like processing of fish Target Strength (TS) measurement. Beamforming is processed inside the echosounder in time domain using programmable electronics. Signals are then decimated at 35 kHz, demodulated and filtered before being transferred to the topside through an Ethernet Gigabyte link. It has to be mentioned that Seapix architecture does not show any latency between the transmission and the receiving sequences. Therefore, the surface blind zone is only related to the transmitted pulse length. For example, a pulse length of 1ms leads to a blind zone of 75 cm.

An Inertial Motion Unit (IMU) is embedded in the MBES, allowing real-time motion stabilization of the beams in transmit and

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receive. Embedded IMU also significantly mitigates the calibration procedures for installation offsets calibration, reducing calibration to the GPS/Heading sensor alignment and latencies compensation. To this respect, Seapix can be seen as a stand-alone MBES, only requiring GPS and heading sensor ancillaries.

Seapix can be supplied through 110/220V AC or 36V DC and synchronized as master or slave. The hull-mounted part, containing antennas and all the transmit/receive electronics uses wet mateable connectors allowing diver installation or refit. The weight of Seapix is 53kg in air and 27kg in water. Subsea cable is 20m long and is connected to interface unit in the sonar room.
All processing are made in the Beamforming Unit and Man Machine Interface and displays are realized using a Visual Processing Unit running the Seapix software based on ECDIS certified software. BFU and VPU are placed on the bridge. A real time output stream to Olex has been implemented and validated. Data acquired by Seapix can be converted to several file types such as HAC, or XTF, and other outputs format are currently under development.
Seapix is currently installed on more than 50 industrial fishing and fishery research vessels across the world.

The original architecture of SeapiX makes it possible to also analyze bottom using multiple settings such as transverse and longitudinal swathes. This new type of multi beam echo sounder (MBES) based on steerable symmetrical Mills Cross [2] is able to electronically steer swathes in the fore or aft direction of the vessel. This peculiarity provide the ability to exploit more swathes angles than conventional MBES without the need of a mechanical pan and tilt structure that would be necessary to move beams to specific directions. This paper describes two examples of application made possible by such feature.

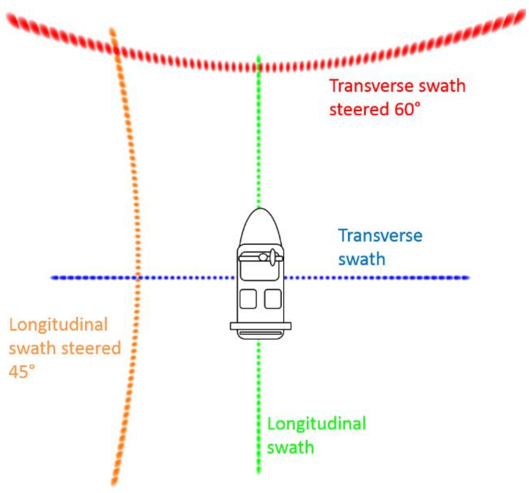

Figure 1 multiple swathes example electronically steered

The first example describes how the use of several tilted swathes may improve significantly bottom hardness measurement based on backscattering strength (BS). By extension, a bottom classifier will be thoroughly described. The second example address Seapix ability to scan a surface without any displacement of the vessel, which may be a major gain of time for dredgers that wish to check progress while digging or leveling bottom floor.

Multiple swathes imaging as a tool for bottom classification

The measurement of backscattering strength (BS) is a function of the grazing angle

The backscatter profile provides very efficient information on the bottom type. However, as the grazing angle is close to specular, all kinds of seabed appear the same (figure 2, BS at 90°). By steering the incident beam, differences between all kinds of seabed increases, and discrimination starts to become feasible. In practice, this kind of measurements are noisier than these ideal curves displayed on figure 2.

Figure 2 theoretical BS curves as a function of grazing angle for several types of bottom floor (figure from GeoHab workgroup report may 2015, data source University of Washington Applied physics lab)

As previously mentioned, Seapix ability to steer the transverse swath provides complementary information to the conventional BS measurements. A conventional survey was performed in la Ciotat bay across classified seabed from SHOM. The area was composed of sand, dense posidonia, and sparse posidonia.

The area was surveyed using three differents swath configurations. The configurations are alternate at each emission ping : conventional transverse emission at 0° from nadir, transverse forward emission tilted at 20° and emission in the longitudinal direction.

Figure 3 left : waterfall of BS measurement from transverse swath, right : BS from transverse swath steered 20° forward

On figure 3, the two transverse emission configurations are compared. The angular dependence of BS across sand is clearly visible on the transverse swath (left) and is mildly attenuated on the tilted transverse swath (right). This waterfall display already provides a good insight of the interest of the multi-swath capabilities.

The waterfall display of the BS obtained using emission on the longitudinal axis is shown in figure 4. The BS profile for each insonified pixel at nadir is then directly visible. On the figure, we can clearly distinguished the different type of seabed. However, the information is only acquired for pixel that are on the vessel trajectory and is sensitive to yaw.

Figure 4 waterfall like image based on BS from longitudinal swath

To classify the seabed, a way to proceed is to consider both longitudinal and transverse swath. On transverse swath the features used for classification are the local mean and variance of the BS signal. So we call this method the level based method. During the learning process, seabed homogeneity is assumed across each swath. Using a classical Bayesian classifier, the confusion matrix (table I) shows a good classification rate between the posidonia and the sand.

Table 1 confusion matrix of the profile based classification on the transverse swath data (%)

%	Dense posidonia	Sparse posidonia	sand
Dense posidonia	87	13	0
Sparse posidonia	10	85	5
Sand	1	2	97

On the longitudinal swath, the feature extracted is the full BS profile, so we called this method the profile based method. In that case no homogeneity assumption is needed. A nearly 100% classification rate (Table II) is obtained excellent classification rate, even between the two type of posidonia (dense and sparse). This very good result demonstrates the efficient capability of the BS profile to discriminate against different seabed types. Specific details of the implemented methods are described in [4].

Table 2 confusion matrix of the profile-based classification on the longitudinal pixel based data (%)

%	Dense posidonia	Sparse posidonia	sand
Dense posidonia	100	0	0
Sparse posidonia	3	97	0
Sand	0	0	100

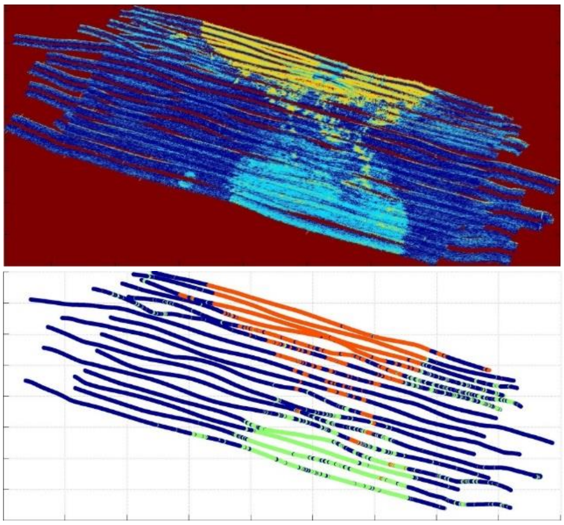

Figure 5 Up : Mosaic from level based method (transverse swath), bottom : classification from profile based method (longitudinal swath)

On figure 5 , the classification maps of the two methods are displayed. On top, the results obtained using the level-based. Each pixel across swath except near nadir is classified. The three classes are clearly segmented, but some confusion near frontier of the regions are visible. On bottom, the classification map obtained using the profile based method is shown. Only pixel on the vessel trajectory are classified but with much less confusion in between classes. Distinction between sparse and dense posidonia are very well defined.

Static bathymetry from electronically scanned beams

Another advantage of the Seapix steerable reversible mills cross, is the ability to scan a volume from a static position. This is particularly interesting for dredging applications, where it is necessary to verify whether levelling has been performed correctly. This very turbid environment is not suitable for cameras optical sensors, nor sophisticated hydrographic MBES mounted on pan and tilt mechanical interface.

After exploring several ways to robustly detect the seabed with the best reliability, a method was proven to be quite efficient. It consists in an iterative extrapolation algorithm. Initialization of a reliable zone is performed on a small angular sector, which is not impacted by side lobes [3]. In that manner, if the transmission grazing angle progressively increases with a redundancy between consecutives footprints, a relatively narrow detection area around precedent detections will follow the main lobe footprint, even for high grazing angle where specular reflection of side lobes could be higher than signal coming from the main lobe.

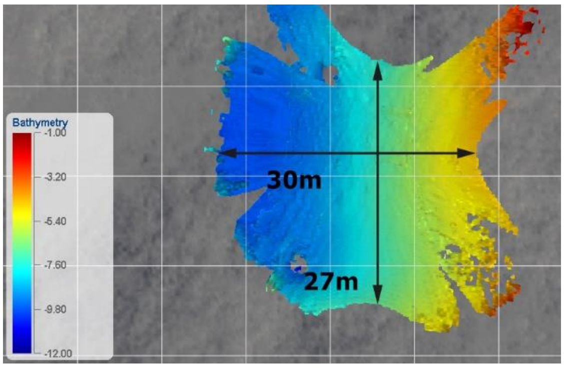

Figure 6 first result of the iterative extrapolation algorithm applied on an electronically scanned surface. Perpendiculars antennas were alternatively switching between transmission and reception.

Even if this method provides a first result, it was improved by exploiting complementary data between two orthogonal scans. As depicted figure 7 (left), phase detection quality is pretty bad around central angles. To circumvent this phenomenon, exploitation of antenna reversibility let us convert transmission angles into virtual receiving angles. For instance, to virtualize a swath from a transversal scan with a 40° angle, it is possible to convert all receiving lines from 40° for each transmitting scan (figure 7, right). This method provides smoothly defined phase detection in all directions. To summarize, the use of amplitude detection from both scans and the extraction of phase detection from real and virtual swathes provides four choices for each detection. The best detection will then be the one having the best quality coefficient (figure 8).

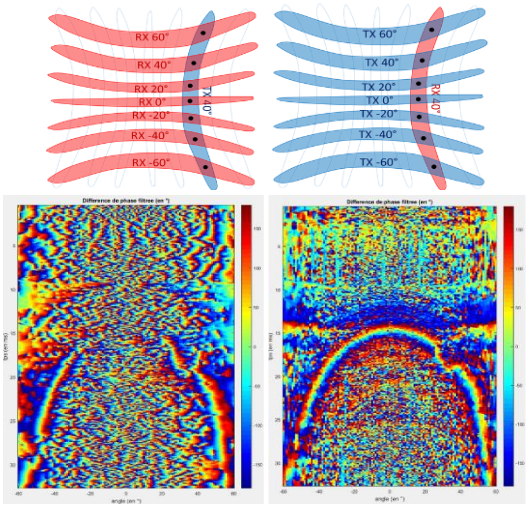

Figure 7 Left : conventional swath, right : virtual swath

Detections based on amplitude are located within a solid angle of 20° (green and yellow dots; figure 8) which corresponds to the specular reflection of the bottom floor since Seapix was installed with an installation offset of 20°. For higher grazing angles, phase detection from both longitudinal and transverse swaths had higher quality factor (red and blue dots). Finally, the improvement of extracting the phase information from virtual swathes resolves artefacts that are corrected by the use of virtual phases. The use of virtual phases improves significantly sounding accuracy [3].

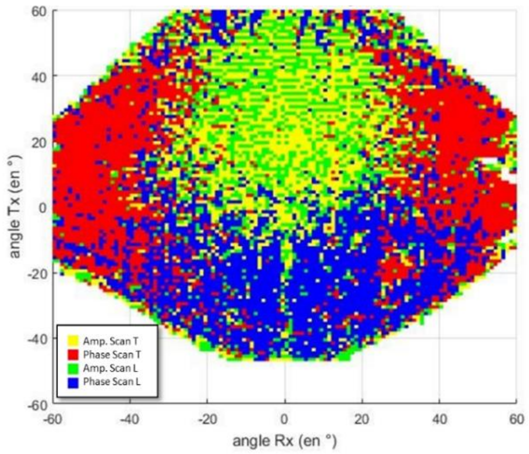

Figure 8 Detection choices for each beam according to quality factor

CONCLUSION

The use of Seapix innovative methods to exploit data from perpendicular steerable swathes provides real benefit in terms of performances in very specifics applications such as bottom classification or static bathymetry in turbid environment.

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