SHADOWS, A SYNTHETIC APERTURE SONAR, BY IXSEA

F Jean IXSEA SAS, La Ciotat, France

1 INTRODUCTION

Ixsea has developed a new real-time processing synthetic aperture sonar completed with a frontscan gapfiller. The sidescan modules are working at 100 kHz and the length L of the antenna being 2 meters. At this frequency, with a wavelength λ of 1.5cm, a classical processing would lead to along-track resolution δ of only 2.25m at the range R of 300m .To improve this resolution, one solution is to form a long virtual antenna by coherently adding successive pings (Fig. 1.). Moreover, the length of the rebuilt antenna can be adapted to the range; therefore the resolution is range-independent.

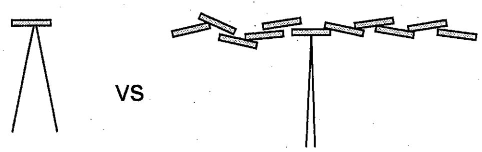


Fig. 1. *Classical vs. Synthetic aperture sonar*

This is the main principle of Synthetic Aperture Sonar. The theoretical resolution is only limited by the directivity of the transmitter, related to its length Le. The theoretical resolution considering that the towed fish is moving on a straight line without any other movements is Le/2. This is not realistic as long as our towed fish is passive. In our design, we have considered the real resolution to be twice the theoretical one i.e. Le.

The main concern when doing SAS processing is to avoid lacunarity of the virtual antenna. To prevent this, acquisition of the data has to be made following a strict rule which is that the displacement between two recurrences should not be greater than L/2, the half of the length of the physical antenna, i.e. the length of the equivalent transmitter/receiver antenna (Fig. 7.a.). The equivalent transmitter/receiver antenna is obtained by replacing each couple of physical transmitter and receiver by an equivalent transmitter/receiver located in-between.
The limit for this displacement is L/4 when the classical ping to ping cross-correlation (P2C2) is used. We will see that we can avoid this last limitation by using the ping-pong P2C2 described in section II.
Setting c = *1500m/s*, the speed of sound, the assessments for the maximal range R and the sonar length L fix the maximal speed v to be allowed (1.1).

$$v = \frac{L \cdot c}{4 \cdot R} \tag{1.1}$$

In the Shadows configuration, the maximal speed without using ping-pong P2C2 is 2.5 knots. But the Shadows are allowed to reach 5 knots.

2 ARCHITECTURE

2.1 General

With the design of Shadows (Fig. 2.), the resolution reaches 15cm at a maximum range of 300m and the maximum speed to form a nonlacunar synthetic aperture is theoretically 5 knots. The coverage rate reaches 5.56 square km per hour.

The Shadows system (Fig. 3.) is made of a fish with two sidescan sonar antenna designed for synthetic aperture acquisition, a frontscan sonar [5] to image the gap at nadir and two PCs : one dedicated to acquisition of the signals, and the other one to perform the SAS algorithm and computes the images. The images are shared through a network and are visible on any PC connected, equipped with NASA World Wind.

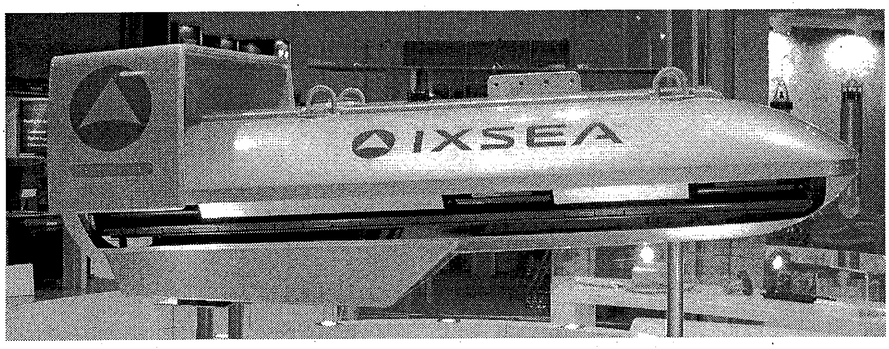


Fig. 2. *Shadows*

Each side is composed of a receiver array of 24 hydrophones and three transmitters. Two of the transmitters are located at each extremity of the physical antenna in order to perform ping-pong P2C2.

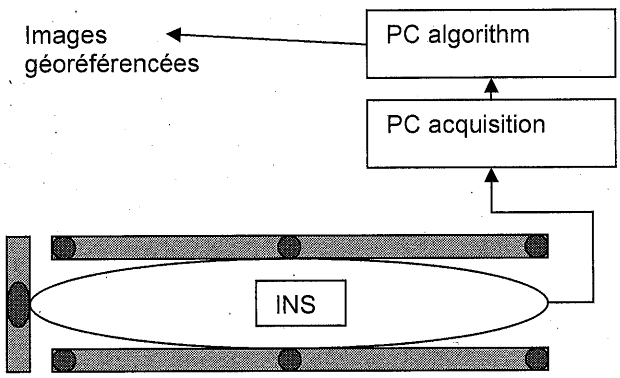


Fig. 3. *Shadows general architecture*

The six transmitters of the sides are identical. The length of those transmitters is 14cm, therefore the theoretical along track resolution is 7cm and the practical resolution is 14cm along the swath. The central Frequency is 100 kHz and the bandwidth is 30 kHz. This bandwidth is divided in three. One main part which width is at least 20 kHz is used for imagery on the central transmitter. Two other narrower parts are used for the ping-pong P2C2. The signal is recorded on each receiver and demodulated. The separation of the different transmitted pulses is done by three different convolutions.

2.2 Prototype

The first step of the development program has been to build a sonar prototype working at a frequency of 150kHz. The bandwidth of the signal is 8kHz. In this configuration, the performance are lower than for the final system. The theorical along-track resolution is 7cm at a range of 250m, but regarding the fish movements and the bandwidth we prefer to deal with a square precision of 20cm x 20cm.

With this prototype, we have done a survey of La Ciotat Bay during January and February 2006.

3 ALGORITHM

3.1 3d rebuilt of the path

The main issue in Sas processing is to rebuild the synthetic antenna along the path of the fish. In the Shadows, we use a synchronized and accurate INS in order to calculate in 3 dimensions the whole synthetic antenna geometry

The first reason we can rebuild precisely the 3d path of the towed fish is because the INS that we are using is very accurate. In particular, the error on the angles (heading, roll and yaw) is around 0.0001 degree for the time of integration. This is negligible.

The second reason is that we use of a log giving a speed to the INS, ensuring that there is only a linear drift on the absolute positioning (Fig. 4). We are currently working on replacing the Doppler log by the use of a sonar log. This will use the correlations of the sonar data to calculate a speed vector. The data given by the log are used by the Kalmann filter of the Ins. This permits to control the drift on the position. This factor drift is about 0.001 for the shadows application. This is sufficiently low to allow a centimetric relative precision during the formation of the synthetic aperture which is about a few seconds. To obtain a resolution of 15cm at 300m, the length of the path to take into account is 15m. At 5 knots, this takes 6 seconds.

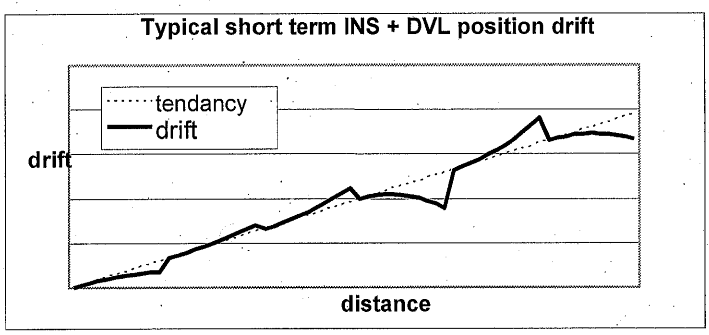


Fig. 4. Typical short term INS aided position drift.

The theoretical influence of the drift has been detailed in [6]. By comparison of the directivity of the real and drifted antenna, we can see that the effect is a slight shift on the image position and a very low increasing of secondary lobes on Fig. 5.

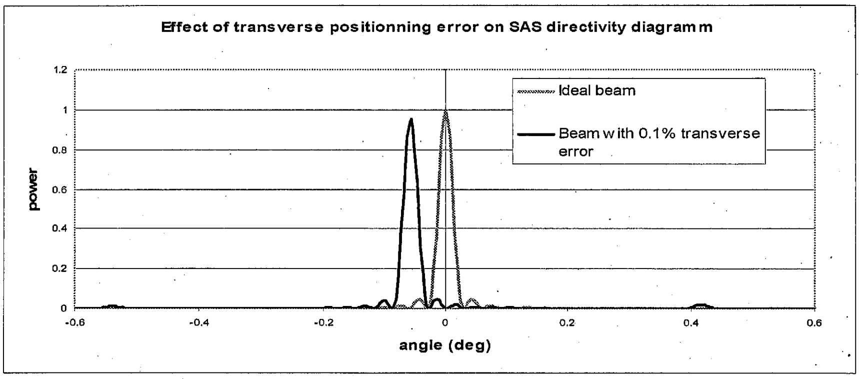


Fig. 5. *Effect of transverse positioning error on SAS directivity diagram.*

Though we unfortunately can not avoid the short-term drift, it can be corrected on the images in the long-term by the use of a USBL like GAPS.

3.2 Remaining corrections mainly due to topography: P2C2

Despite the very accurate rebuilding of the path, there are still some corrections to do in order to focus correctly. They are mainly due to the evolution of depth of the sea bottom along the 300 meters swath and to the influence of the underwater environment on the acoustic signal.

A first approximation can be made by asserting that the sea bottom is flat. We first set the depth to be equal to the depth measured right under the sonar. In most of the cases this hypothesis is reasonable. In Fig. 6, we show different focuses on a 37m x 15m image at a range of 100m assessing different depth values. There are two 10 m long pipe and a block on the left end of the right pipe. The real depth of the scene is in this case around 30m. We observe that the general textures of the images are the same. If we look on images with smaller targets, we can see a light defocusing when we leave the reasonable values for depth.

Anyway, we improve the focus on the images including depth errors and underwater environment influence, by computing the P2C2 algorithm ([2]). This consists in calculating three coefficients (L, β and τ in Fig. 7) between two consecutive pings by correlation of the corresponding signals.

Those coefficients can not lead to the 3d reconstruction of the path. They are in fact a combination of the six movements (three angles and three displacements), of the bathymetry of the sea-bottom and of the underwater environment. By comparing those coefficients with the results given by the INS, we focus more correctly on the images. As long as the main effect of defocusing is due to the evolution of depth along the swath, we are now working on an algorithm which computes a calculation of the topography by comparing the P2C2 coefficients and the INS data.

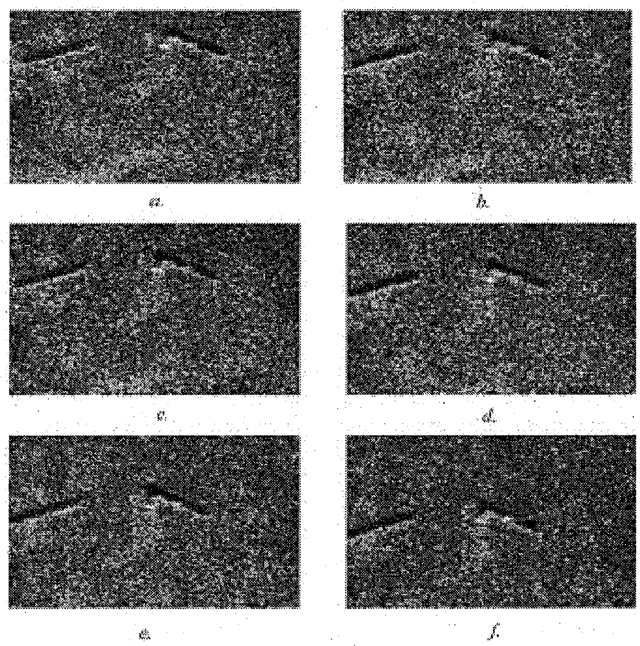
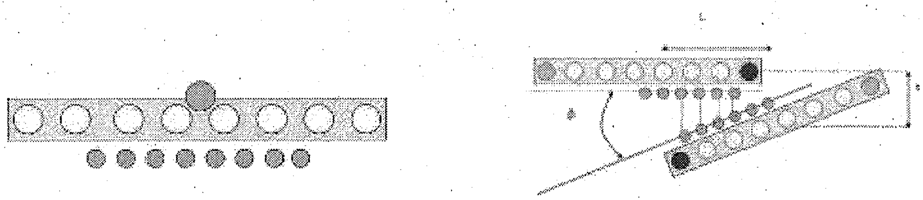


Fig. 6. *Focus of a 37mx 15m image on different depths.*
a. depth 15m. b. depth 20m.
c. depth 25m. d. depth 30m.
e. depth 35m. f. depth 35m.

With a classic SAS system, a good correlation is obtained when at least one half of the equivalent Emitter/Receiver antenna is in correspondence. In this case, maximum speed would have been reduced to 2.5 knots to calculate pertinent P2C2 coefficients.

In the Shadows system, we use a patented ping-pong technique described in [3]. Two more transmitters are located at each extremity of the antenna. They emit alternatively two different frequencies (in red and green in Fig. 7). The P2C2 algorithm is performed on the signals corresponding to the front transmitter of one ping and the back transmitter of the following ping. In this configuration, all the equivalent transmitter/receiver are in correspondence from one ping to the following. The theoretical maximum speed for a nonlacunar antenna (5 knots) is thus the better configuration for the P2C2 algorithm.



a. *b.*

fig. 7. . *a. equivalent emitter/receiver antenna:*
in blue the transmitter
in yellow the receivers
in orange the equivalent transmitter/receiver.
b. P2C2 with auxiliary frequencies

3.3 Real-time Beam forming, Georeferenced Images.

Beam forming is computed in real time. The method used is time domain fast factorized back projection described in [1] or [4]. It consists in factorizing the calculations by doing some acceptable approximations. The limitations of the approximation are range dependant. Further the target is located from the sonar, less precise the calculation has to be. This allows the calculation to be fast and precise enough.

When the images are computed, we use the absolute georeferenced position given by the Phins. Hence, the images are directly georeferenced on a map. A first advantage of this is to avoid image deformations due to the fish navigation. A straight line on the sea bottom remains straight on the image, and is continuous from one line to the other. A mosaic is built and providing that the phins is aided by a USBL, the absolute positioning is very precise.

We can follow the difference of the sea bottom texture boundaries on several lines (Fig. 8).

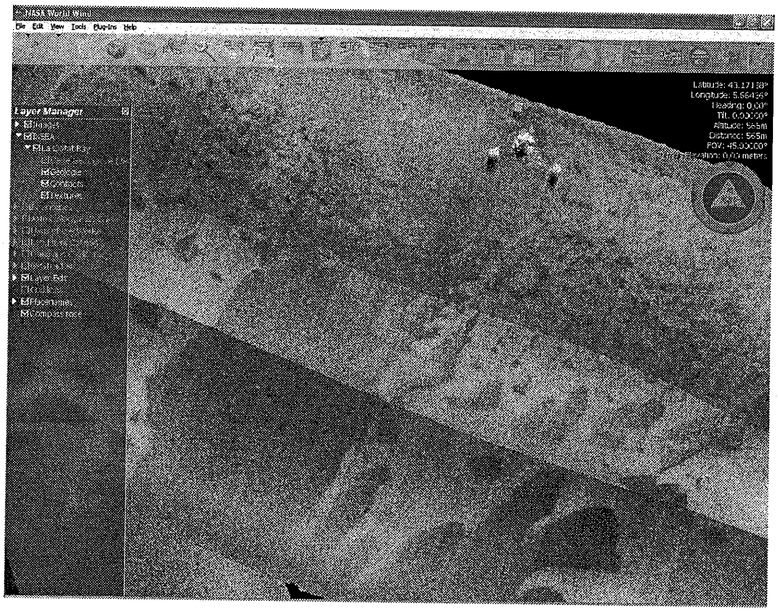


Fig. 8. *Continuous textures on three different sonar lines.*

The visualisation is done on NASA WorldWind, with the use of a map server. This allows different users to look simultaneously at the images formed.

4 SUMMARY

The first step of the Shadows project has shown that synthetic aperture sonar can display high resolution georeferenced images in real time. The next step, which is already in progress, is to realize the Shadows Product which will have a longer range and will be more accurate. It will also include a topography calculation of the sea-bottom.

5 REFERENCES

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