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Wideband Synthetic Aperture Mapping of the Sea Bottom

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Seabed survey using wideband synthetic aperture sonar can provide high resolution images and maps (a cubic meter voxel at a few kilometres range) using a reasonable array size (2 metres) and a rather low frequency range (6-12 kHz) .A low frequency prototype has been constructed in the frame of the MAST project SAMI "Synthetic Aperture Mapping and Imaging". A large amount of experimental data was obtained at sea and stored for further processing. The paper will show some of these results. It will display both synthetic images and 3D maps.

1. Introduction

As the aperture of an array is inversely proportional to its length in wavelengths, increasing the resolution for a standard sidescan system can be achieved in two ways:

- increasing the array length: the major limitation encountered will be the manoeuvrability of the tow fish or

- increasing the central frequency: the major limitation will be the decrease of the maximum range and thus of the coverage rate.

The synthetic aperture is the best way to break the relation between the array aperture and the wavelength. It consists in synthesising a long virtual array (small angular aperture) using a physical array of small size (large aperture).

The objective of the SAMI project (Synthetic Aperture Mapping and imaging, EC funded MAS2 project) was to show the feasibility of such a technique.

2. Methodology

In the framework of the SAMI project, the work has been achieved in co-operation between several partners:

- two university laboratories: CPE Lyon, LASSSO (France) and University of Newcastle upon Tyne, DEEE, Underwater Acoustics Group (UK),

- two research centres: IFREMER (France) and Danish Maritime Institute (Denmark) and

- one industrial partner: Reson A/S (Denmark).

The methodology used during the project is described in Fig. 1.

It consists in interactive back and forth actions between system design, numerical simulations, scaled tank experiments, prototype design and construction, sea trials (with real-time processing on board) and data post-processing. A total of four campaigns were conducted at sea.

The experience learned from the first ones was used for refining the prototype design and improving its performances in the final experiment.

3. Prototype description

The prototype description is given in Fig. 2. It consists in two parallel receivers and a single transmitter integrating in a tow fish together with an inertial measurement unit. The tow fish was connected to the ship by a fibre optics tow cable and the processing was achieved on board.

The performances of the prototype are summarised in table 1.

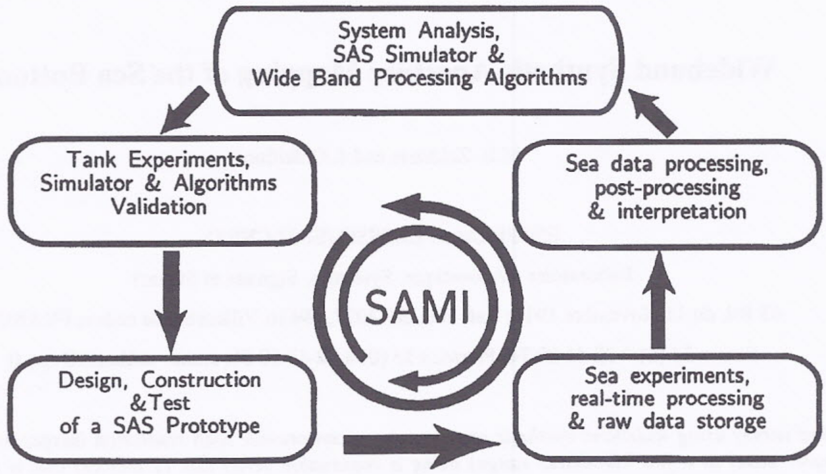

Fig. 1. SAMI project methodology.

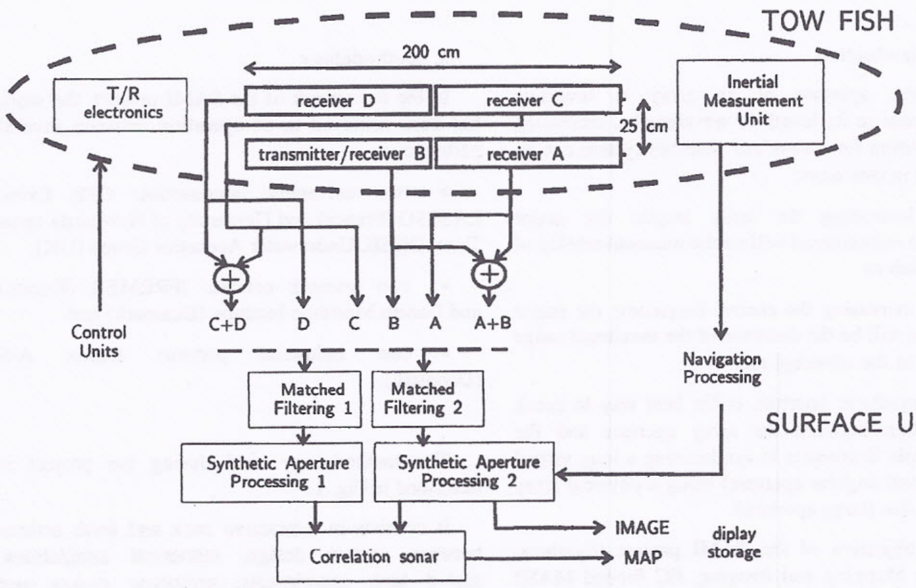

Fig. 2. SAMI prototype description.

Table I. Prototype characteristics.

SIGNAL CHARACTERISTICS	
Frequency Range	5-10 kHz (@-6dB)
Transmitted Level	218 dB ref. 1mPa @ 1m.
Signals	LPM 10 to 100 ms
Ping Rate	0.34 to 6.8 s

GEOMETRY	
Towfish Length	4 m
Transmitter Length	1 m
Receiver Length	2 x 1 m
Transducers Height	0.26 m
Immersion	< 250 m
Tow-Speed	3 knots typ.

EXPECTED PERFORMANCES	
Across-Track Resolution (after pulse compression)	0.3 m
Along track resolution (range independent)	1 m
Area Coverage Rate (500m swath)	2.7 km^2/hour

The tow fish containing the arrays and associated electronics was a neutrally buoyant vehicle.

It was used as a sub-surface system (immersion < 250m). It contained 4 arrays (1 transmitter/receiver + 3 receivers) that were used for imaging and mapping in both standard and Vernier (to increase the coverage rate) modes.

A bottom navigation unit was used to estimate the tow fish behaviour and to correct its influence either on-line or off-line.

The transmitted signals were Linear Period Modulated chirps with variable duration (10 to 100 ms) and a time-bandwidth product of 50 to 500.

The transmitted level was as high as 218 dB over the frequency range.

The surface unit contained several sub-units for:

- system control (signal selection, gain, TVG, level, ...)
- navigation data processing,
- real-time pulse compression,
- real-time synthetic aperture processing,
- data display and
- data storage.

4. Sea Trials and Results

Several sea trials were conducted first to validate the principle then to produce synthetic images and maps.

The validation trials were conducted using tetrahedral reflectors (point targets) laid on the bottom. The results are displayed in Fig. 3. This figure shows the image of a point target reflector before and after synthetic aperture processing. It also shows how the echoes can be used, in the case of a bright spot for estimating the tow fish navigation and correcting its effect on sonar images (autofocusing).

The estimated fish stability, in this case was about 4.7 cm during 30 seconds.

The expected azimuthal resolution was 1 meter. The resolution obtained was:

- 1.6 m ± 0.1 m without autofocusing and
- 1.1 m ± 0.1 m with autofocusing.

The image contrast was also enhanced by more than 3 dB by autofocusing.

After validation the method on standard targets, the system was used to obtain synthetic aperture images on extended areas.

Fig. 4 show a typical example illustrating the effect of dynamic focusing (i.e. azimuthal resolution is constant with range) in the case of a rocky area.

In the unprocessed image, one can see that, in the very close range, rocks can be distinguished and their shadows can be clearly identified. The resolution is getting worst and worst as range increases (the azimuthal resolution decreases with range) and far rocks cannot be separated and isolated any more while, in the synthetic image, the resolution being constant with range, all the rocks can be distinguished and their shadows visible at any range (and are comparable in size).

It is important to note that this is the very first low frequency images (kHz range) where shadow of objects of about one meter are so clearly seen at a range of 500 m.

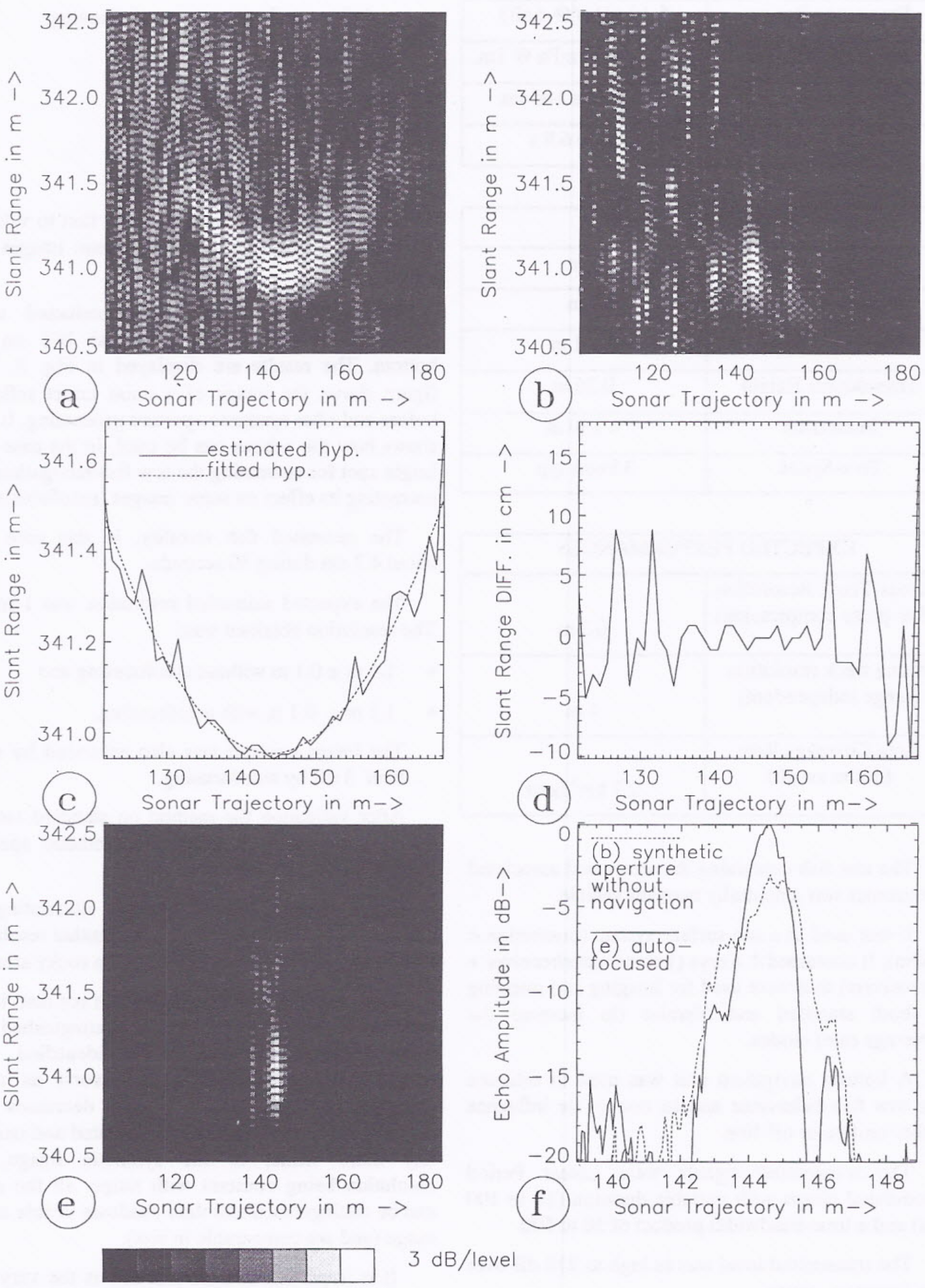

Fig. 3. Sonar image of a tetrahedral reflector; a) raw image, b) synthetic aperture image, c) estimated echo delays (with best fit parabola), d) navigation error, e) synthetic image after autofocusing, f) azimuthal cross section of image b) and e) at the target position.

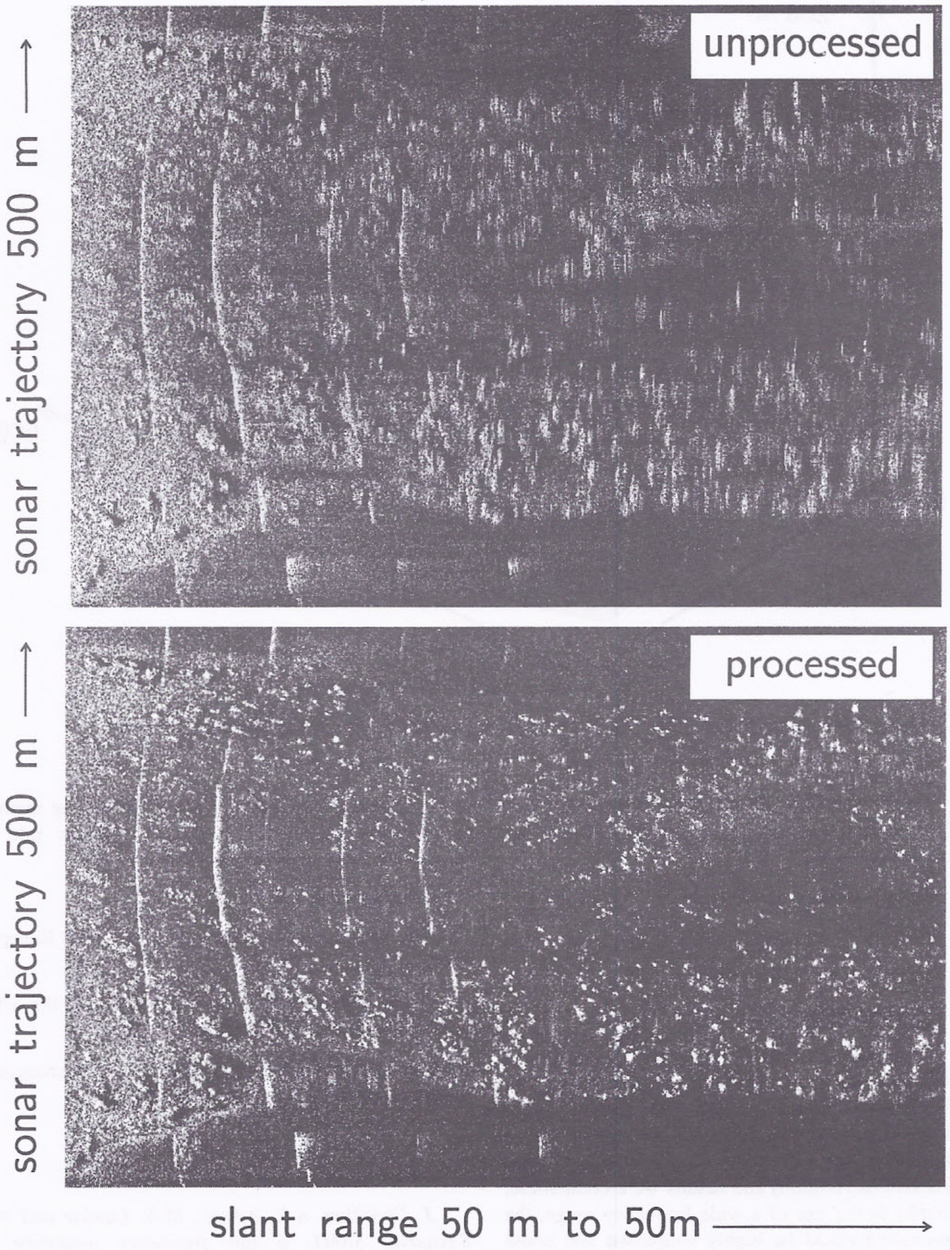

Fig. 4. Imaging of rocks in shallow water (linear grey scale).

Several images similar to Fig. 4 have shown the image quality enhancement due to the use of synthetic aperture.

While using two parallel arrays (A+B, C+D; cf. Fig. 2), it was possible to compute stereoscopic images of a given area. By using the echo delay (between both arrays), it was then possible, for each point reflector and each reverberation cell, to compute the angular position and build up a map of a given area.

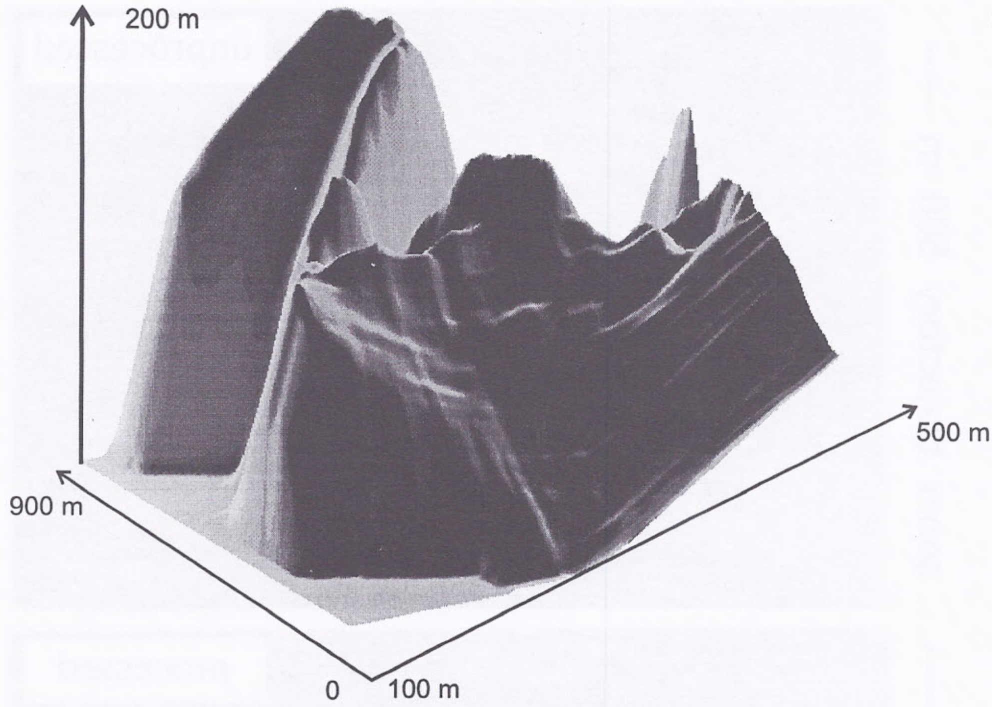

Fig. 5. 3D reconstruction of the Var Canyon area (scales 500 m x 500m elevation 500 m).

Fig. 5 shows a 3D reconstruction of the Var Canyon area. The resolution obtained for this 3D reconstruction is:

Range resolution: 0.3 m,

Azimuthal resolution: about 1 m,

Elevation resolution: about 1 m.

5. Conclusion

The SAMI project has clearly shown the possibility of using synthetic aperture techniques for bottom mapping. The 3D images maps obtained were compared to the one obtained by a high frequency (100 kHz) deep tow system (100 m above the bottom) and results were compatible. Thanks to the use of a wide frequency range, the processing could be highly simplified and could run in real-time on board with a "reasonable" amount of dedicated processors (40 transputers and 64 filters controllers): a swath of 750 m was processed in real-time on board. The spectral content of the echoes is presently under investigations and several complementary methods for autofocusing have been studied and applied on small areas (for computation time reasons). The extension of these autofocusing methods as well as the increasing of the coverage rate are interesting challenges for the future.

6. Acknowledgements

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7. References

J. Châtillon, A.E. Adams, M.A. Lawlor and M.E. Zakharia, SAMI: a low frequency prototype for mapping and imaging of the seabed by means of synthetic aperture, IEEE Journal of Oceanic Engineering, vol. 24,n°1, pp. 4-15, (1999).

V. Riyait, M. Lawlor, O. Hinton, and B. Sharif, Real-time synthetic aperture sonar imaging using a parallel architecture, IEEE Trans. Image Processing, vol. 4, pp 1010-1019, (1995).