Conférence Méditerranéenne Côtière et Maritime
EDITION 1, HAMMAMET, TUNISIE (2009)
Coastal and Maritime Mediterranean Conference
Disponible en ligne – http://www.paralia.fr – Available online

Sonar advancements for coastal and maritime surveys

Mohammed SANHAJI [1]

1. EdgeTech, 1141 Holland Drive, Bay 1, Boca Raton, Florida 33487, USA.
   sanhaji@edgetech.com

Abstract:
The beam forming echo sounders are the predominantly popular system because of their accuracy and coverage speed however their inefficiency in shallow waters and high prices have given the interferometric type and edge particularly after the recent advancements which include:
- Frequency modulated "chirp" technology for increased range
- Multi-pulse technology for high speed surveys
- 8-Receiving channels for increased detection
- Long arrays for high resolution imagery at range
- Co-registered simultaneous side scan

Keywords:
Interferometric sonar – Multibeam echo sounders – Sub-bottom profilers – EdgeTech

1. Introduction

The Mediterranean basin and continental margin is subject to environmental hazards such as earthquakes, landslides, floods, and tsunamis as well as widespread pollution and coastal erosion. The Mediterranean Sea also contains important resources such as hydrocarbon fuels, groundwater, as well as coastal wetlands and fisheries.
The selection of correct sonar system for a specific application is difficult for engineering firms that are venturing into the marine environment. This paper attempts to provide information on the latest available technologies, mainly for sub-bottom profilers, side scan and swath bathymetry sonars to gather accurate high resolution seafloor imagery, seabed morphology and bathymetric data necessary for any coastal or maritime engineering project.

2. Frequency modulated techniques for sonar systems

Sonar systems that use the frequency modulated (FM) pulses and advanced signal processing techniques provide higher resolution and increased range/penetration over sonar systems with band limiting components.
Frequency modulated systems also referred to a "chirp" uses amplitude and phase weighting functions for the transmitted pulse and a correlation filter to compress wide band signals.

DOI: 10.5150/cmcm.2009.074-9

Chirp systems use a broad bandwidth transmitting pulse that sweeps out over a range of frequencies. This generates a great deal of acoustic energy in the water. Instead of trying to operate with one very sharp acoustic peak pulse, like conventional CW systems, FM systems spread the transmission out over long time duration. In addition, to the range improvement, the process of correlation processing achieves a signal processing gain over the background noise. This gain is approximately ten times the log of the time-bandwidth product. To equal the typical performance of chirp sonar, conventional pulsed sonar would have to operate at a peak pulse power 100 times larger.
Normally, when using long pulses the resolution of the sonar is lost. However, resolution of chirp systems is obtained after correlation processing of the received signal. This is because the output of the correlation is a very sharp wavelet that has duration of the order of the inverse of the sweep bandwidth. Thus, the more bandwidth used, the sharper this pulse will become.

3. Side scan sonar advancements

3.1 Dynamic aperture / focusing of the sonar array

Most conventional side scan sonar systems offer dual frequency operation; providing a low frequency for long range target detection (with decreased resolution) and a higher frequency for increased resolution (with decreased range) once the target has been identified. Dynamically focused technology is a way to overcome this thread off as it is able to provide higher resolution imagery at longer ranges. In the past this technology was typically found only in expensive military sonar systems but it is now available for commercial offerings at an affordable price.
The along track resolution of a side scan sonar is typically specified as the half power angles (–3 dB points) of the beam width in degrees. This is due to the fact that for most of the range covered by such a system the beam shape is best approximated as a diverging wedge with a constant angle (θ) dictated by the length to wavelength ratio (D/λ). Very close to the transducer this is not true, and the beam does not converge on a single, narrow point at the transducer.
In the region close to the transducer, the linear beam width is best approximated as about $0.5*D$, where D is the unit's physical length. Beyond this region, the beam diverges at the angle stated as the angular beam width in degrees. It is readily apparent from this that the along track resolution of a transducer is never less than about one half its length, and that at longer ranges the linear beam width is approximately $R*\theta$, where R is the across track range to the target. The angular beam width can be estimated from the formula: $\theta = 3000/(F*D)$, where F is the frequency in kHz, and D the length in inches.
Making the array's physical length (D) much longer to reduce the beam angle has the effect of reducing the array's near range resolution. It is thus not possible to design a

conventional single element side scan array with both good near and far range performance, and the final design is a compromise between these two extremes.

3.2 Focusing

The limitations, imposed by the physics of the situation, may be overcome if the array is physically curved to match the radius of curvature of the sound waves impinging on the device.

Like the ripples from a pebble dropped into a pond of water, the echoes that radiate from a target reflecting the side scan sonar's transmit signal similarly radiate outwards with a circular wavefront, with ever increasing radius, R, the distance between the wavefront and the target.

If the array is curved with a radius of R, it will be focussed at this range, and it will be optimized to produce the best resolution at this range. While it is possible to construct such a physically curved array, it is both awkward to make and has the disadvantage of only being focused at one range. The effects of a curved array can be approximated closely by a multi-segmented array consisting of a number of short linear elements (see figure 1). The curvature required for the focusing is achieved by applying the correct electronic delays to the elements, prior to summing to form the array's output. The delays applied are also dynamically altered with time to allow focusing at each range sample of the sonar.

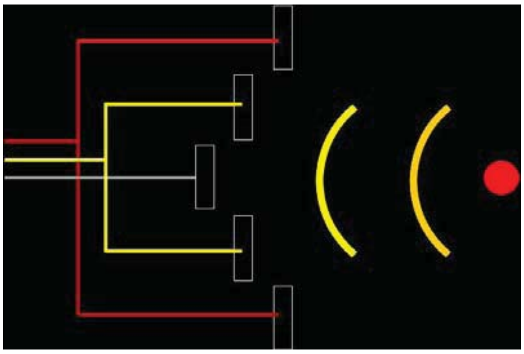

Figure 1.

An example of the image improvement offered by such processing is illustrated in the side scan data sample. The data shown in figure 2 is from a dynamically focused system operating at 900 kHz. The range scale at the right is in meters. The image on the left is the unfocused sum of the sub-elements, which closely approximates a typical array size for this frequency. The image on the right is the result of summing the individual elements with appropriate focusing information. The increase in image sharpness is readily apparent, as is the increase in signal to noise ratio at farther ranges.

The improvements offered by dynamic focusing techniques and the use of modern DSP allow for efficiencies that can be achieved by using a lower frequency sonar, with much larger range, with the same resolution as a higher frequency system. The increase in range achievable for a given along track resolution may be as large as a factor of two, effectively doubling the coverage rate.

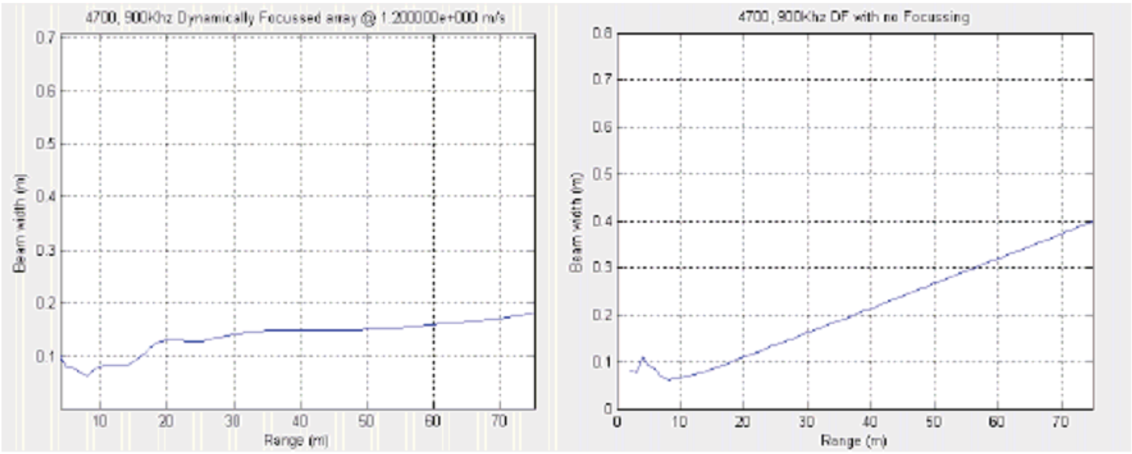

Figure 2.

3.3 Aperture

By utilizing a multi-element construction of the array (see figure 3), the sonar dynamically changes the array aperture to optimize the sonar's resolution in the near-field region. The transducer array in a side scan sonars with Dynamic Aperture is programmed to receive just on a few elements at a time or all the elements at once.

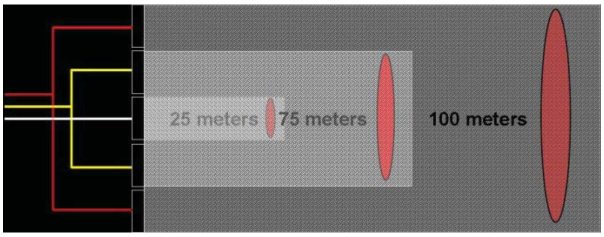

Figure 3.

3.4 Multi-pulse sonar

Conventional side scan sonar systems are limited in transmit-receive cycle times by the sound propagation velocity of 1500 m/s. Following the transmit pulse the sonar system has to wait for reception of the echo data from the farthest range before the cycle can repeat (see figure 4). This restriction results in ping rates that are adversely affected by range, and can severely limit the tow speed of the side scan sonar.

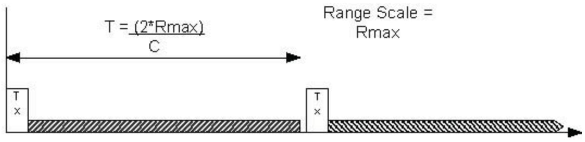

Figure 4.

Multi-ping side scan sonar can transmit pulses during normal reception, without any cross pulse interference. This technique allows sonar ping repetition rates at 2, 3, and even 4 times those achievable with standard sonar.
NOAA survey requirements ask for a minimum of 3 hits on a 1m target located at 150m range. Using a conventional sidescan sonar the survey speed must be limited to 3.2 knots to meet this criteria.
The survey speed can be increased 4 times by transmitting multiple, distinct pulses at a higher rate as shown in figure 5.
The NOAA requirement for "3 hits on a 1m target" at the 150 m range setting is now exceeded at 12 knots.

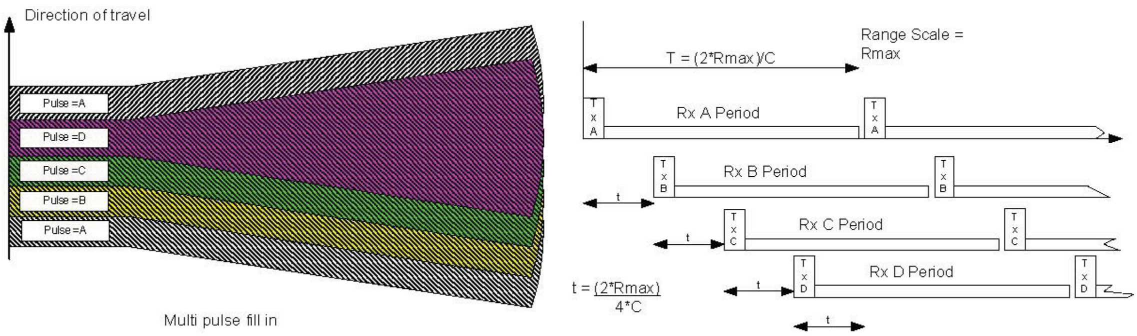

Figure 5.

3.5 <u>Swath bathymetry sonar advancements</u>
A swath bathymetry system is one that is used to measure the depth in a line extending outwards from the sonar transducer. Current swath bathymetry systems utilize two differing technologies to achieve bathymetry measurements across a "swath" of the sea floor:

- Beam forming (Multibeam echo sounders (MBES)) which electronically form a series of transmit and receive beams which measure the depth to the sea floor in discrete angular increments across the sonar swath.
- Interferometric or phase discrimination sonars which use the phase content of the sonar signal to measure the angle of a wave front returned from a target. The range is calculated from two-way travel time. The angle is determined by knowing the spacing between elements within the transducer, the phase difference of the incoming wave front and the wavelength.

4. Conclusion

Combining side-scan sonar data collection with chirp sub-bottom profiling and Swath Bathymetry along with ground-truth sediment samples, can be used for mapping, over large area extents, bottom sediment distributions within estuarine, coastal settings and open ocean.

The integrated chirp sub-bottom profiles provide additional information on bottom sediment type, and provide the sub-bottom perspective that is lacking if the side-scan data were collected stand-alone. In particular, the sub-bottom data provides important constraints on the lateral continuity of bottom sediments and can be used to map thicknesses of these units (MADSEN & SOMMERFIELD, 2003).

5. Reference

MADSEN J.A., SOMMERFIELD C.K. (2003). *Application of side-scan sonar, sub-bottom profiling, and echo-sounding techniques to study sediment deposition and erosion in estuaries: Results from the lower Delaware River and upper Delaware Bay*. U.S. Hydro'2003 Conference, March 24-27, 2003, Biloxi, Mississippi, USA. Available online [URL http://www.thsoa.org/hy03/2_3.pdf]