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RESEARCH ARTICLE

CHALLENGES OF VISUALIZING THE SEAFLOOR WITH MODERN SONAR SYSTEM

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ABSTRACT

Aperture synthesis enables a high azimuth resolution from a physically small array. The technique has been highly successful in radio astronomy, satellite and aircraft borne radar. However the use of this technique has been limited to sonar because of difficulties of maintaining a stable track under water and problems of under-sampling of the aperture arising from the relatively slow velocity of acoustic waves. This paper describes the application of the synthetic aperture technique to sonar, highlighting some of these difficulties and possible means of overcoming them. Geometry is developed to measure the height of objects and to produce 3-D image.

INTRODUCTION

The seafloor has increasingly become the subject of attention and exploration. Sidescan sonar images are a visible representation of the strength of the acoustic back scatter from the sea floor onto a 2-D image medium. The concept of a synthetic aperture (SA) is to synthesize an aperture by sampling as an array or element moves along a given path. Difficulties facing an acoustic attempt at forming a successful SA were apparent from the start and have restricted the application to underwater systems. Motion irregularities and media turbulence, causing phase errors, must be corrected (M. A. Pinto, 2002). The relatively slow acoustic propagation velocity in water implies a low pulse repetition frequency leading to the consequences that large amount of irregular and unknown motion in the transducer path can occur between pulses (S. Reed, Y. Petillot, and J. Bell, 2003). The multipath pattern of propagation can exhibit significant instability in this period and the coherence between the pulses is not easy to maintain (R.Sathishkumar and A.Vimalajuliet, 2009).

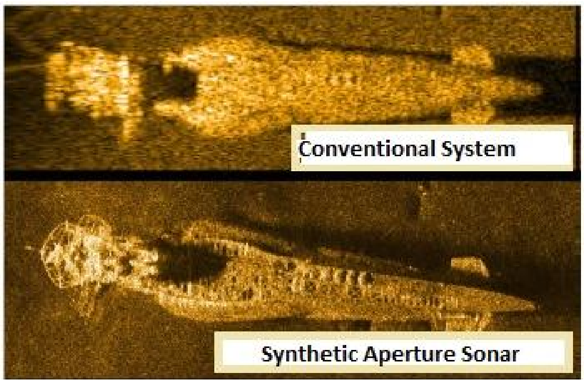

Figure 1. Conventaional vs Synthetic Aperture sonar

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Synthetic Aperture Sonar

Synthetic aperture sonar (SAS) with sophisticated post-processing produces a very narrow effective beam (Afif Belkacem, Kamel Besbes, et al, 2006). In the frequency range of 70–100 kHz, it produces ultra high resolution images as shown in Figure.1. With the INS navigation, motion sensing and modern signal processing such as DPCA (Displaced Phase Centre Analysis), produces a resolution of about 4 cm both along track and across, each beam being processed from 40 consecutive pings. It is implemented by mounting a single transducer on a moving platform such as towfish, from which a target scene is illuminated. The echo waveforms received successively at the different positions are detected and processed together to resolve elements in an image of the target region (T. O. Sæbø, R. E. Hansen, and A. Hanssen, 2007).

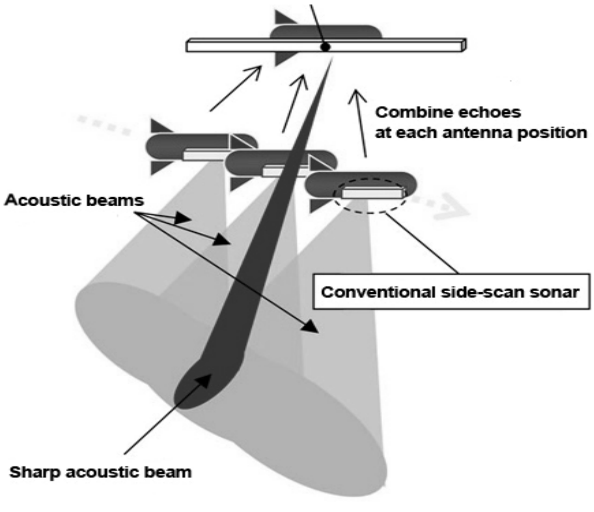

Figure 2. Syntheic Aperture Sonar Operation

Processing Algorithms

Software simulation, which produces simulative echo and images, is important for testing different image formation algorithms, studying the interaction of acoustic waves with a scene, testing and validating of different system design parameters and is an economical method in research. The figure.2 shows the typical SAS operation. Simulations are done in time domain (creates a high-precision raw data, but has low computational efficiency), frequency domain (processing complexity) and hybrid domain (inverse imaging). The first generation of processors used the power series expansion of the range equation in time domain and range Doppler domain (Bellettini and M. Pinto, 2008). It is the most widely used algorithm because of its favorable tradeoff between maturity, simplicity, efficiency, and accuracy (J. Groen, R. Hansen, H. Callow, et al, 2009). However a high computing load is experienced when a long kernel is used to obtain high accuracy in the Range Cell Migration Correction (RCMC) operation. Also it is not easy to incorporate the azimuth frequency dependence of SRC, which can limit its accuracy. The chirp scaling algorithm eliminates the interpolator used for RCMC. It is based on a scaling principle whereby a frequency modulation is applied to a chirp encoded signal to achieve a shift (V. Myers and J. Fawcett, 2010). The algorithm has the additional benefit that Secondary Range Compression (SRC) can be made in azimuth frequency dependent. This benefit arises because the data are available in the 2-D frequency domain at a convenient stage in the processing. It decouples the pulse and energy and gives finer resolution. The required range-variant RCMC shift can be implemented by using phase multiplies instead of a time-domain interpolator. After range is compressed with the new frequency modulated rate, displacement occurs at the location of the signal, which makes target range curvature in frequency domain that has the same shape in different range. In Continuous Transmission Frequency Modulation (CTFM), the along-track velocity of the towfish is not determined by the pulse repetition rate, but determined by the frequency resolution of the spectrum analyzer that converts the output into target strength versus range display. Hence the range resolution can be traded off to enable the sonar to move with a higher velocity covering the wanted SA in a shorter time. The increase in velocity alone will produce an improvement in the performance of system as the surrounding medium has less time to alter its character significantly. This collection of frequencies is used as input to a spectrum analyzer for decomposition into individual components and subsequent display.

Motin Error and Compesation

SAS suffers the upper bound on the pulse repetition frequency imposed by the relatively slow sound speed in water (H. J. Callow, M. P. Hayes and P. T. Gough, 2009). This limits the platform velocity and introduces motion errors more easily due to the ocean instabilities like waves, water currents and wind.The successful application of the SA relies on the accurate knowledge of the transducer trajectory (G. Fornaro, G. Franceschetti, and S. Perna, 2005).

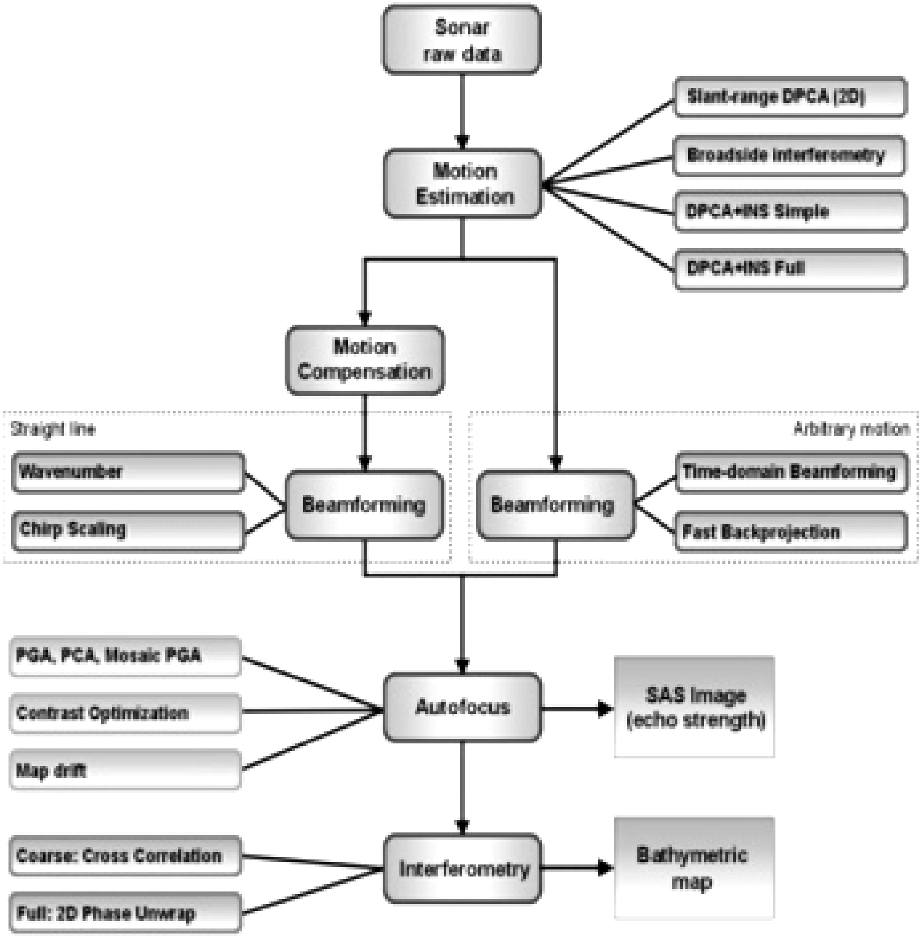

Figure 3. Typical SAS Signal Processing Chain

If the transducer positions are not known precisely the phase errors will be introduced which will seriously degrade the image as shown in Figure.4. Due to this it is difficult to maintain the pulse to pulse coherence and motion compensation needs to be applied. The DPCA exploits the spatial and temporal coherence properties of the seafloor backscatter (A. Bellettini, and M.A. Pinto, 2002). The range migration algorithm or ω-k algorithm, wave number algorithm, seismic migration algorithm, are performed in the 2-D Fourier transform on the raw data or pulse compressed data (R.Sathishkumar and A.Vimalajuliet, 2010). Figure 5 and 6 shows the uncompensated and motion compensated images.

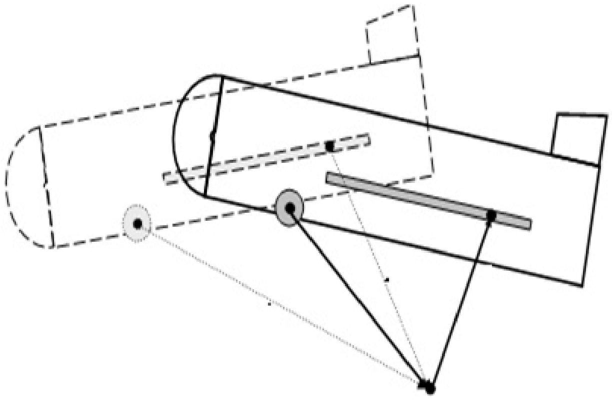

Figure 4. Example for a Motion Error

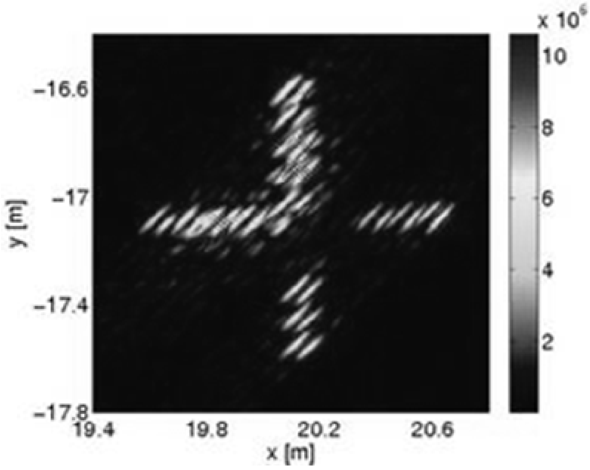

Figure 5. Uncompesated Image

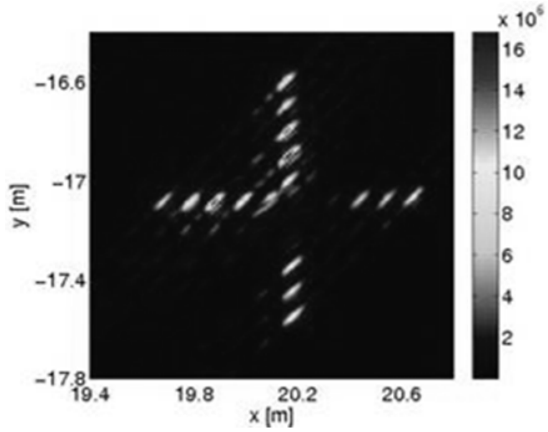

Figure 6. Motion compensatated result

Interferometric Processing

Interferometric SAS (In SAS) system is capable of making high resolution 3-D images that combines image coregistration and height estimation processes as shown in figure.7. Each of the receiver datasets is processed using standard algorithms, with motion compensation and corrective processing, preserving the underlying time delays.

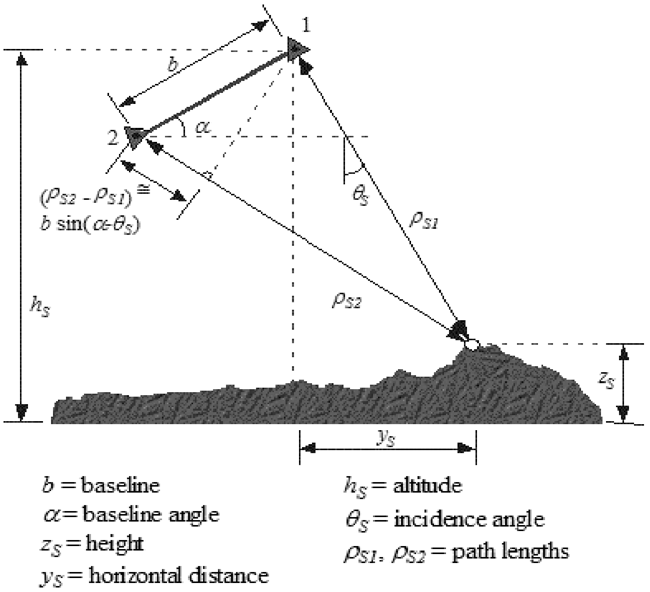

Figure 7. Interferomertic Geometry

Two complex images of the target scene are formed, one using the upper and one using the lower receiver array. Assuming the two images are perfectly co-registered, the interfeogram can be generated. The height of the target scene can be estimated from the phase difference between corresponding pixels in the two images (R. Bamler and M. Eineder, 2005). The fringes are intricately related to the system parameters. If these fringes are closely spaced, the phase unwrapping becomes nearly impossible, contingent upon the noise level and the sampling interval (T. O. Sæbø, R. E. Hansen and A. Hanssen, 2007). It is necessary to determine the relationship between fringe-spacing and system parameters. The vertical fringe spacing as the target height differential required to complete one cycle of interferometric phase, and horizontal fringe spacing, as the equivalent range differential for a flat surface (A.R. Brenner and L.Roessing, 2008). An In SAS simulator can predict echo returns of a given 3-D target scene using a given function for the transmitted pulse. The processing study can be carried out using MATLAB and Figure 8 and 9 shows the typical simulated 3-D images of seafloor.

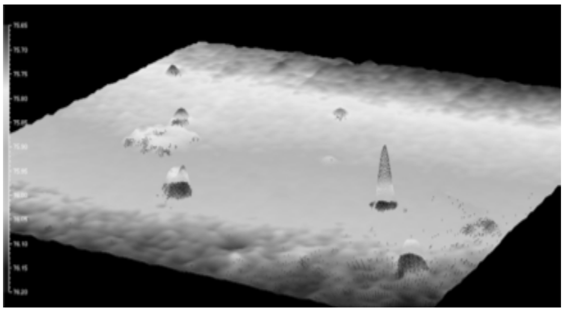

Figure 8. Typical Image Simulated in 3-D imaging Tool

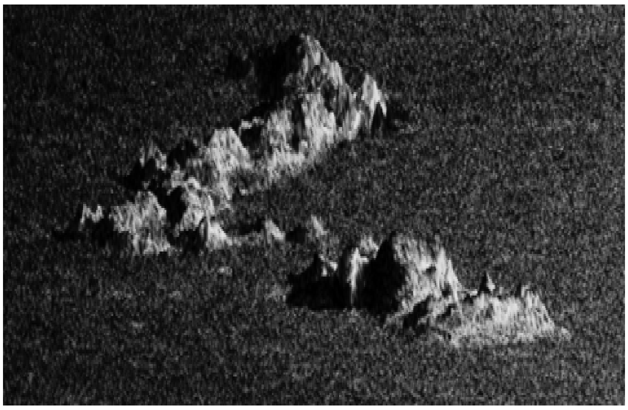

Figure 9. Interferometci SAS Image

Conclusion

We have studied the resolution limits of the time domain and frequency domain imaging and the need for 3-D mapping. The use of SA processing on sonar has been proposed and analyzed. In the future, other processing algorithms, in the frequency domain rather than in the space-time domain, can be implemented in order to improve the computation speed. For more realistic simulations the implementation of a real SAS has to be considered for the generation of 3D objects instead of point targets.

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