PHASE PRESERVING SYNTHETIC APERTURE SONAR DATA FOCUSING FOR REPEAT-TRACK INTERFEROMETRY APPLICATIONS

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ABSTRACT
A Synthetic Aperture Sonar (SAS) system combines the echoes received along a virtual array of hydrophones in order to provide high resolution acoustic images of the seabed. In order to avoid range ambiguity the echoes are collected by a short physical array of receivers mounted on an Underwater Autonomous Vehicle (AUV) [1]. In this paper we present a focusing algorithm suitable for imaging multistatic SAS data. Results achieved by means of the proposed technique will be analyzed on real data collected by means of the Muscle AUV system operated by NURC. This paper presents the results of a 2 year study led by ENI gathering data in several sea campaigns in the Tyrrhenian Sea near La Spezia (Italy). The complete description of the project will be presented at EISOLS 2010.

1. INTRODUCTION
In the framework of sustainable development activities carried out by Eni Exploration & Production division, the Eni Geological Service in association with Eni R&D department has promoted and financed the development and the experimentation of an innovative technology for environmental monitoring. The paper describes the experimental activities conducted in the context of a two-year project with the aim to test innovative approaches to better assess the altimetric accuracy and variations of the seabed. Synthetic aperture Sonar are acoustic remote sensing systems able to provide acoustic reflectivity maps of illuminated areas. In this paper a wavenumber domain focusing algorithm for SAS data will be discussed in detail and results achieved by means of the proposed technique will be analyzed on real data. The focusing of SAS data has to cope with different problems: the variations of the acoustic wave speed, the actual platform trajectory that is not rectilinear and that is not precisely known, the multistatic nature of the acquisition system since data are collected by a short physical array that moves along time. In section 2 we describe the acquisition geometry and the parameters of the system used to collect the data. The focusing algorithm is described in section 3, while section 4 contains the results achieved applying the proposed technique on real data collected by means of the Muscle AUV system operated by NURC. Moreover, a multipass SAS interferogram will be shown in order to check the focusing quality and to illustrate the achievable coherence of the sea-floor at the experiment site.

2. SAS ACQUISITION GEOMETRY
The data are acquired by a sonar mounted on a AUV system that moves on a nominal rectilinear trajectory. Fig. 1 shows the acquisition geometry: the squares represent the successive positions of the acquisition system during time on the along track direction \(x\). The echoes of each transmitted ping are received by a physical array with 36 receivers. Fig. 2 shows the travel paths of the acoustic wave front from the transmitter to the target in \((\xi, \rho)\), and from the target to each of the receivers.

The impulse response of the system, after range compression and assuming a stop and go acquisition, can be written as:

\[
h(x, t) = p\left(t - R_f(\xi, \rho) + R_a(x; \xi, \rho)\right) \frac{c}{c} \exp\left(-j\omega_0 R_f(\xi, \rho) + R_a(x; \xi, \rho)\right)\]

Where \(p(t)\) is the transmitted pulse after range compression, \(t\) is the fast time, and \(\omega_0\) is the carrier wavenumber.

Figure 1: Multi ping acquisition geometry
Table 1: System parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>300 kHz</td>
<td>Central Frequency</td>
</tr>
<tr>
<td>$c$</td>
<td>1500 m/s</td>
<td>Sound speed</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>5mm</td>
<td>Wavelength</td>
</tr>
</tbody>
</table>

Figure 2: Single-ping acquisition geometry

3. SAS FOCUSING

The general approach used to focus SAS data consists mainly in two steps. In the first step we focus the echoes of each ping independently, obtaining low resolution focused images of the area. In the second step we coherently sum these focused images, obtaining the full resolution reflectivity map of the observed area. In order to sum coherently the data collected during different pings we need to compensate for the actual position and orientation of the platform during time.

3.1. Sub aperture image focusing

The echoes of a single ping collected by the physical array are focused by means of a modification of the standard Omega-K technique. The Omega-K technique is an efficient phase preserving focusing technique widely used in the Synthetic Aperture Radar (SAR) field [2]. This technique has been modified by the authors and integrated with dedicated processing steps to provide a precise phase preserving SAS focusing [3]. The focusing technique for single ping data is shown in Fig. 3. The raw data of the nth ping, $d_n(x,t)$, are first transformed in the azimuth direction and multiplied for the function $H_{mot}$ that takes into account the motion of the platform between transmission and reception. Then we transform the data in the fast time direction and apply the Stolt interpolator and the focusing kernel for bi-static data, $H_2$. Finally we multiply the data with the functions $H_3$ and $H_4$ that takes into account the travel time from the transmitter to the targets. $H_3$ is applied in the domain $(\xi, k_\rho)$ and $H_4$ in the two dimensional space domain.

3.2. Full aperture image focusing

The sub-aperture focused images are then coherently combined to obtain the full resolution reflectivity map of the observed area. We compensate for the irregular motion of the platform by exploiting both the available navigation data and by inverting the inter-ping interferometric phase pattern. The processing for multiple ping data focusing is summarized in Fig. 4.
4. RESULTS

In this section we discuss the results achieved applying the whole focusing algorithm on real data of the sea floor. Fig. 5a shows the amplitude of a focused image that is a portion of the observed area at the experiment site (Cinque Terre, Italy). Since the same area was observed with multipass acquisitions, we have focused the same portion of data acquired after a time interval of 20 minutes with respect to the master image. After image co-registration we have obtained the interferogram in Fig. 5b, that shows the amplitude of the interferogram colored with phases. It's clearly visible that there is high coherence of the sea bed with this temporal baseline together with fringes due to the differential AUV motion.

5. CONCLUSION

We have presented a focusing technique suited for SAS data. The technique takes advantage from modification of the standard Omega-K algorithm for the single ping focusing, while multiple ping imaging is obtained by modeling the inter-ping phase pattern. We have shown focusing results achieved applying the proposed technique to real data. A multipass SAS interferogram has been shown with a temporal baseline of 20 minutes between acquisitions. The interferogram has revealed high focusing quality and high coherence of the sea-floor at the experiment site. The real data are available in the framework of a project leaded and supported by ENI S.p.A, whose complete description will be presented at EISOLS 2010.

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7. REFERENCES

