Detection of Internal Waves Using Multi-Aspect Processing in Synthetic Aperture Sonar

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Abstract

Refractive effects may cause artifacts in synthetic aperture sonar (SAS) imagery and interferometry processing. These effects may appear as natural seabed features in the data products, and are difficult to detect as water column induced features. We propose to use a technique based on multi-aspect processing applied to the SAS data to detect the water column induced features. The technique has been tested and demonstrated on real data from an interferometric SAS collected by a HUGIN autonomous underwater vehicle from the ARISE'12 trials conducted by NATO research vessel Alliance owned and operated by Centre for Maritime Research and Experimentation.

1 Introduction

Synthetic aperture sonar (SAS) has matured substantially in the last decade, and is today an established technology for seabed imaging and mapping. The similarity between SAS and its counterpart in radar, synthetic aperture radar (SAR), is striking [1, 2].

In October 2012, the Norwegian Defence Research Establishment (FFI) participated in the ARISE'12 sea trial onboard the NATO research vessel Alliance hosted by the Centre for Maritime Research and Experimentation (CMRE), off of Elba island, Italy. The main tool was FFI's HUGIN autonomous underwater vehicle (AUV) (**Figure 1**) with an interferometric SAS [3] operated in repeated passes. Large linear structures parallel with shore were observed to change between passes. These structures were visible both in the SAS images and in the interferometric SAS bathymetry estimates. It was concluded that these artificial features are caused by the refractive effects of lower sound speed water-column structures formed from breaking internal waves [4, 5]. Similar type phenomena have also been observed in airborne SAR [6, 7].

In this paper, we investigate a specific technique for detecting such artificial features in data from a single pass. The technique is based on applying multi-aspect processing to the SAS images [8, 9, 10] in combination with observation of the particular motion of the artificial features induced by the refractive effect. This motion is similar to motion from a moving shadow in multi-aspect processing [10, 11].

2 Images from Repeated Passes

Figure 2 shows SAS images collected by the HUGIN AUV on repeated passes over the same area during the ARISE'12 trial. The temporal separation is 5 hours, and the images are coregistered to within a few pixels. The images are formed using the backprojection algorithm in a ground range plane [3].

Figure 1: The HUGIN autonomous underwater vehicle equipped with the HISAS wideband interferometric synthetic aperture sonar.

The image resolution is slightly better than 4 x 4 cm, and the images have not been despeckled. The AUV depth is around 38 m, and the altitude is around 17 m. This gives a grazing angle of approximately 12° at the centre of the image. The image scene contains a pipeline with anchors, clearly visible and colocated in position in both passes. The wave patterns at 80 - 120 m cross-track position are artificially induced variation in intensity from refractive effects caused by internal waves. The wave patterns are clearly different between the two passes. In a single pass, these features can easily be confused as being real seabed features. They even appear to be natural features in the bathymetry derived via interferometry [5]. In the airborne SAR case [7], the similar effects were interestingly described as *moving hills*, with a clear visual similarity to our data.

A main challenge is therefore to detect, or rather reveal, these features as artificial (i.e. not caused by the seabed texture and topography) in a single pass of data collection.

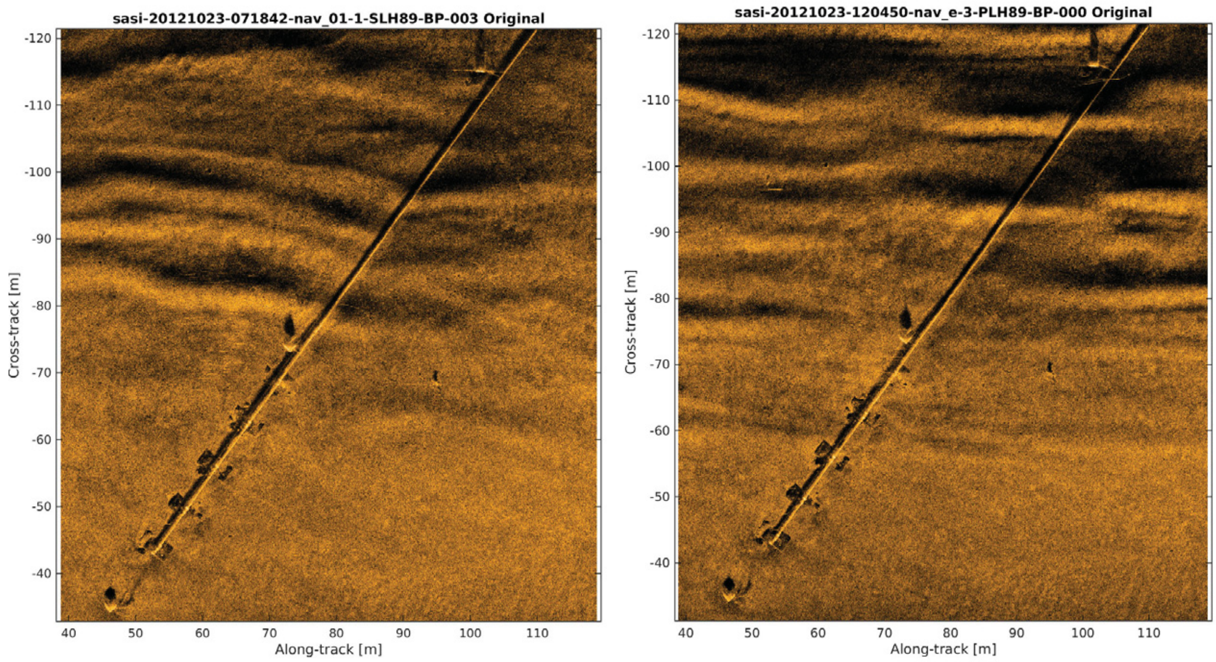

Figure 2: SAS images of the seabed from repeated passes taken 5 hours apart. The image scene is 80×90 m in size. The scene contains a pipeline on the seabed. Note the water column induced artificial wave patterns that differ between passes.

3 Detection Technique

In order to understand how the refractive effect caused by the water column feature (the breaking internal wave) actually cause changes in the SAS image, we investigate a simple idealised ray-tracing example as illustrated in **Figure 3**. An incoming acoustic wave field (or the transmitted signal) will experience ray bending due to the sound speed changes in the water column. This refraction will again lead to a grouping of rays into a highlight area, and a corresponding area of little or no rays (that looks like a shadow area).

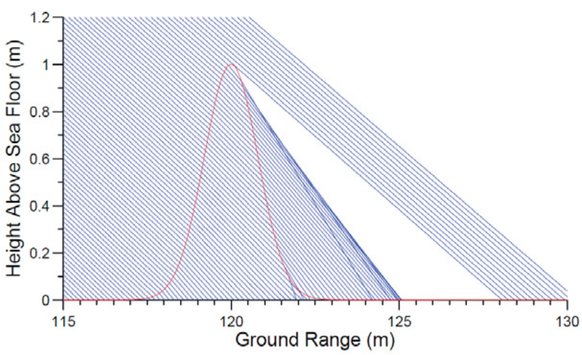

Figure 3: The refractive effect of the internal wave on an incoming acoustic field. Note that the vertical axis is exaggerated compare to the horizontal axis.

The highlight-shadow pattern will appear at a distance greater than the internal wave causing it in the SAS image. This is similar to an acoustically opaque object that casts a shadow (note the relatively horizontal geometry with low grazing angles in the scene).

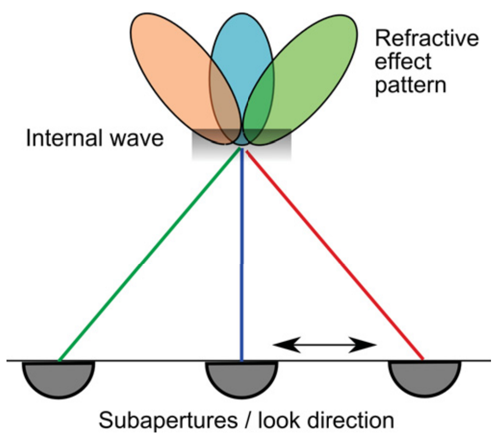

Figure 4: Horizontal movement of the refractive effect of the internal wave as a function of multi-aspect processing.

We suggest the following approach for detecting features seen in SAS images as non-natural (see **Figure 4**):

1. Construct a SAS image in the usual manner and ensure that the image is well sampled

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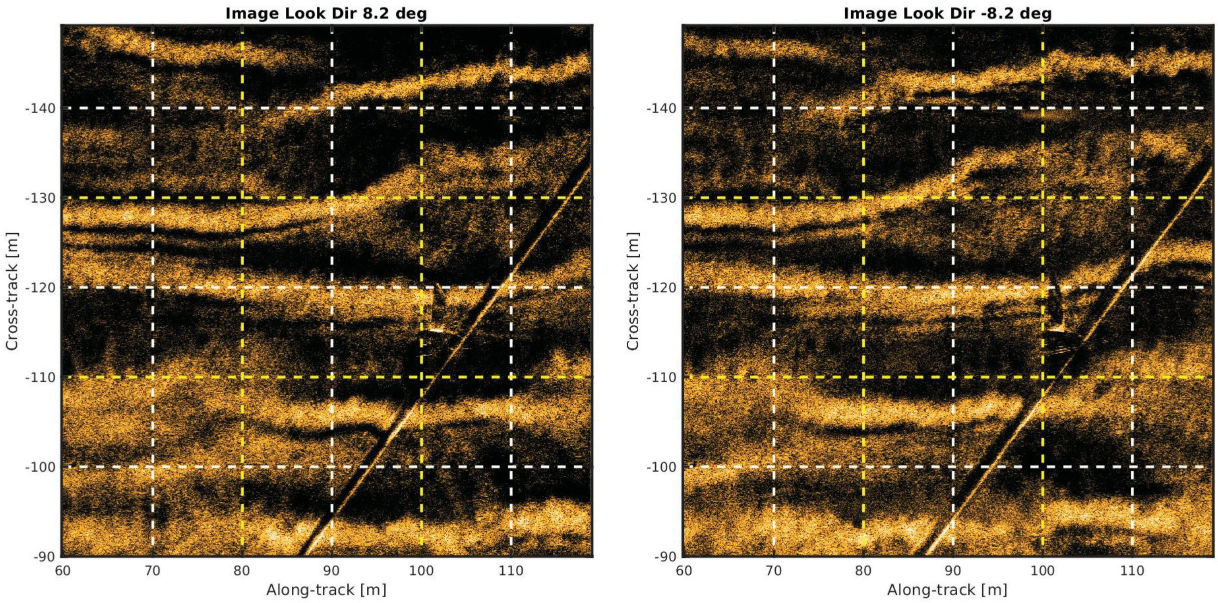

Figure 5: Multi aspect image. The image scene is 60×60 m in size, and the look directions differ with $16.4°$. The data are the same as shown in the right panel of **Figure 2** with a reduced dynamic range.

2. Apply multi-aspect processing to the image [10], and divide into two looks of significantly different look angle
3. Investigate highlight/shadow structures in the images to ascertain if there exists any unexpected movement of seabed features
4. Estimate from geometry the location of the internal wave that caused the refractive effect

This algorithm can potentially be used to detect the water column induced features based on a SAS image from a single pass. There are two potentially interesting applications for this:

- The internal wave structures causing the refractive effect can be located. This again may be used as a means to obtain quantifiable measures on the size of the internal wave structure. These oceanographic features may be important for the dissipation and mixing of nutrients and temperture in shallow waters, and we believe that synthetic aperture sonar is a well suited tool to examine such phenomena. Compared to other means of observing internal waves, such as in-situ probing of temperature, salinity, density, and downwards looking high frequency sonar [12], our technique gives large horizontal area coverage at relatively sparse sampling in time. This may be used to gain information on the internal wave patterns.
- When conducting SAS imaging of the seabed in repeated passes for the application of change detection [13], it is also useful to "flag" observed changes as water colum induced and not actual changes on the seabed.

Note that our suggested procedure in this paper is different from the multi-aspect / multi-aperture technique presented in [5, 14], where the main hypothesis was that different looks corresponds to different temporal images, and that the main change between looks was induced by the actual movement of the internal wave, and not the "moving shadow effect" as described here.

4 Results

Figure 5 shows a multi-aspect processed SAS image, where two looks are constructed using along-track wavenumber filtering. Only 1/4 of the total along-track wavenumber coverage is used in each look, which reduces the resolution along-track by a factor of 4. The image look directions are $\pm 8.2°$, which corresponds to angular difference of 0.28 radians. This means the following. For an intenal wave bolus at 10 m distance from the visible feature in the image caused by the refractive effect (see **Figure 3**), the visible feature will move $10 \sin 0.28 \approx 2.8$ m along-track between looks. The distance between the internal wave bolus and the visible feature in the SAS image is a function of the known grazing angle and the unknown size of the internal wave bolus.

We see in the multi-look images that the wave patterns are shifted towards lower x-values in the right panel, when compared with the left panel. This shift, both in highlight and apparent shadow, is too large to be caused by seabed variations at the position they appear in the images. The only sensible explanation is the one mentioned above. Note that the pipeline highlight structure and the anchors are located in the same position in both images.

5 Summary

Refractive effects caused by internal waves may cause artifacts in synthetic aperture sonar imagery and interferometry processing. We have described a technique based on multi-aspect processing to detect these water column induced features. The technique has been tested and demonstrated successfully on real data from an interferometric synthetic apeture sonar collected by a HUGIN AUV. Potential applications of the technique are in oceanographic studies of internal wave dynamics, and in change detection in seabed SAS imaging from repeated passes.

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