A Technique for Interferometric Synthetic Aperture Sonar Image Processing.

S M Banks† H D Griffiths† and T J Sutton†

† University College London

Abstract: Interferometric Synthetic Aperture Sonar provides a means of obtaining high resolution three-dimensional images of objects on the sea floor. This paper describes a technique for forming images using interferometric sonar data. The technique is novel in the way it combines image co-registration and height estimation. Results of applying the technique to real sonar data are given.

1 Introduction.

Interferometric Synthetic Aperture Sonar (InSAS) provides a means of obtaining high resolution three dimensional images of targets on the sea floor. Three-dimensional information is derived from the phase difference between two sonar images taken from separate receiving arrays. InSAS can be considered to be an improvement on Bathymetric sonar [1] in the way it uses synthetic aperture processing to obtain increased resolution. A large amount of literature exists on synthetic aperture processing, including [2] and [3]. InSAS has many potential applications including seabed topography mapping and mine hunting.

This paper describes improvements to the method described in [4] for obtaining three-dimensional images using InSAS. The method described combines interferometric height estimation and image co-registration into one iterative process; these processes were considered separate in [4]. Results using real sonar data, provided by DERA[1], are given. Other techniques for interferometric sonar processing have also been demonstrated, such as [5]. The theoretical resolution of the technique described in this paper is higher than that described in [5] because it does not require image filtering in the case of noise free data.

2. Interferometric height estimation.

Figure 1 shows the geometry of the InSAS system used for this work. 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 height of the target scene can be estimated from the phase difference between corresponding pixels in the two sonar images using equation 1. In equation 1, the dimensions correspond to those shown in Figure 1, ϕ is the phase difference and λ is the wavelength of the chirp centre frequency. The phase difference between the two images will initially have a 2π ambiguity. This ambiguity is removed using two dimensional phase unwrapping before height estimation. A number of techniques for two dimensional phase unwrapping exist, the method described in [6], originally developed for radar, was used in this work. Other methods, such as the least squares method [7] may also be suitable.

$$r_2 = r_1 + \frac{\phi\lambda}{2\pi}$$

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[1] Defence Evaluation and Research Agency, United Kingdom

$$\theta = \cos^{-1}\left(\frac{{r_2}^2 - B^2 - {r_1}^2}{2Br_1}\right) - \alpha$$

$$h = H - r_1 \cos(\theta)$$

equation 1

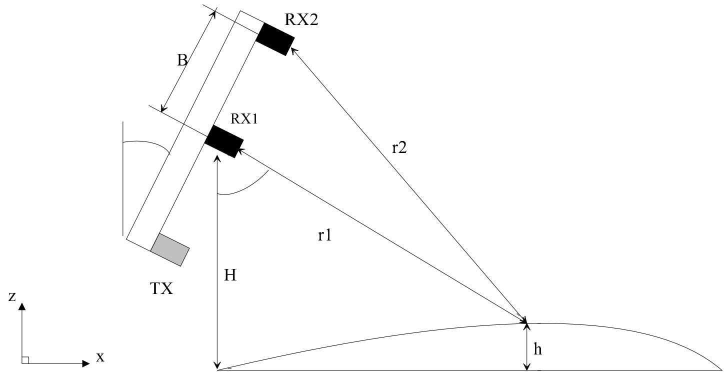


Figure 1 *The geometry of the InSAS system used in this work*

3. Synthetic aperture image co-registration.

Synthetic aperture images are formed by the appropriate summation of many sonar returns received at different locations using a receiver with a broad beam-width. Several techniques for performing this summation in a computationally efficient way have been developed, including [2] and [3]. This process is often referred to as azimuth compression, focusing or inversion.

Most azimuth compression techniques produce an image $I'(r,y)$ with dimensions range from receiver r and azimuth position y. This (r,y) image can be transformed into an image with dimensions $I(x,y)$, where x and y are shown in figure 1, using equation 2. Equation 2 gives the range r in $I'(r,y)$ that corresponds to the pixel $I(x,y)$ in the new image. R_{xy} is the receiver position, T_{xz} is the transmitter position and $P_Z(x)$ is a function of the scene height in x. Because, initially, the scene height is not known, an estimate must be used in the initial image co-registration. Interpolation must be used to perform this co-ordinate transform; Fourier based interpolation was used in this work but other methods may be equally suitable.

$$r(x) = \sqrt{(x - R_x)^2 + (P_z(x) - R_z)^2} + \sqrt{(x - T_x)^2 + (P_z(x) - T_z)^2}$$

equation 2

Errors in the scene height estimate will result in image de-correlation. With low image de-correlation, an approximation to the scene height can still be obtained using interferometry. Hence, an iterative process for finding the target scene height can be implemented by making an initial guess at the scene height, co-registering the images, and forming a better guess using interferometry. This second guess can be fed back into the co-registration process to form two more accurately correlated images. This process can be continued until no further improvement in image co-registration results. The process is summarised in Figure 2.

De-correlation of the images results in an increase in phase noise in the interferogram (phase difference between the two images). High phase noise causes areas termed residues (see [6]) in the interferogram, where unambiguous phase unwrapping is not possible. The image is therefore filtered to reduce the number of residues to close to zero (residues caused by scene geometry, such as layover, will not be removed by filtering) before a height estimate is made. Filtering using weighted averaging was used. Less filtering is required for more closely co-registered images.

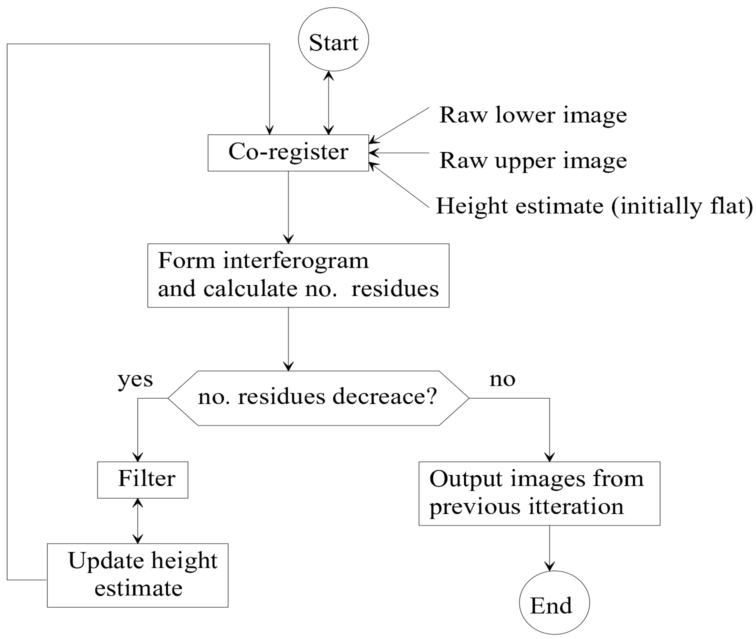


Figure 2 *The iterative height estimation and image co-registration process*

4. Results

The technique described here has been applied to real synthetic aperture sonar data provided by DERA. Figure 3 shows an image of a sphere placed at 15m using a 10m rail. The interferogram formed using the raw sonar images is shown in figure 4(a). The (less noisy) interferogram after the co-registration process is show in figure 4(b). In the figure, colour corresponds to phase.

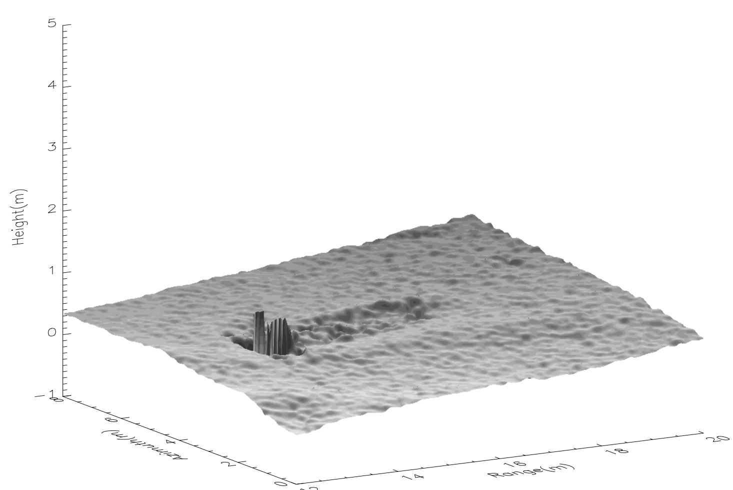
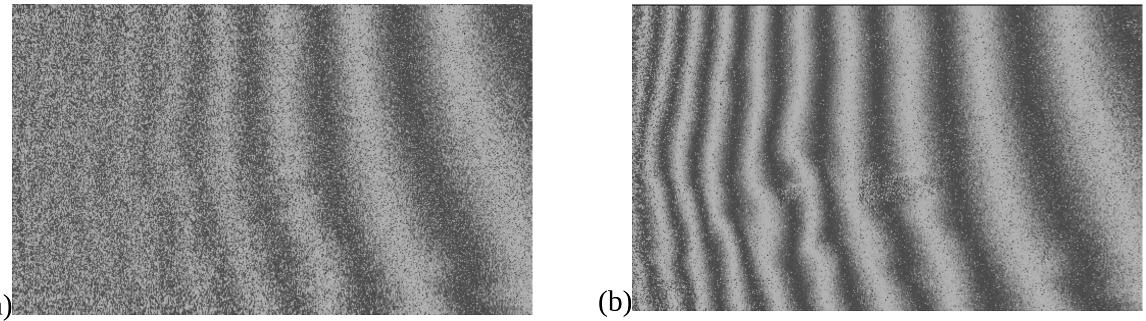


Figure 3 *Three dimensional view of sphere at 20m*



(a) (b)

Figure 4 *(a) Interferogram before image co-registration, (b) after 3 co-registration iterations.*

5. Conclusions.

This paper has presented a technique for combining image co-registration and interferometric height estimation into one process. It has been demonstrated to work with real synthetic aperture sonar data. The technique may fail with images where phase ambiguities arise as a result of scene geometry. In such situation, the phase estimate could be grossly wrong, causing an incorrect height estimate. Such problems may be corrected by combining the technique with image co-registration based on cross correlation also. This will be the subject of future work on the project.

References.

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