RADON TRANSFORM FOR INTERNAL WAVE DETECTION AND ORIENTATION

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ABSTRACT

This paper studies the feasibility of using the Radon transform to detect and orientate internal wave features from SAR images since it seems to be well suited for extracting quasi-linear features even at low signal-to-noise levels. The approach is based on the localized Radon transform where the intensity integration is performed over short line segments rather than across the entire image. The results of this testing demonstrate the algorithm's robustness in the presence of speckle noise, as well as its ability to detect, localize, and orientate internal wave features that are significantly shorter than the image dimensions or that display some curvature.

1 INTRODUCTION

The manifestation of internal wave packets on SAR ocean images has always been of considerable interest to oceanographers. If, as seems likely, the grey tone patterns of these images can be confirmed to correspond to trough and crest patterns of internal waves, then a great deal can be learnt about internal waves from satellite data. Historically, oceanographers have given careful attention to internal waves and their side effects, for they can significantly influence oceanic current measurements, undersea navigation, antisubmarine warfare operations, and even the feeding habits.

The goal of this work was to develop a computer-based method for internal wave detection and orientation in which dark quasi-linear structures, with a high probability of being an internal wave, are automatically identified. Although time-scale methods, such as the *wavelet transform*, have been excellent tools for automatically detecting and characterizing internal waves from SAR images, it does not give good information about the orientation of the detected internal wave packet [1]. Futhermore, for the problem of the internal wave characterization, it requires the creation of SAR image profiles from the detected internal wave packets for parameter extraction [2]. Thus, a method which does not require explicit extraction of line profiles from SAR images for the internal wave characterization problem is desired.

Internal waves can be approximated as straight lines over limited spatial extents. Over larger areas, the internal wave curvature becomes evident. The degree of curvature of an internal wave packet is governed by the internal wave phase speed (which is dependent on the in-water stratification conditions). Thus, the problem presented in this paper is one of quasi-linear feature detection. These quasi-linear internal wave features not only have a certain finite length but also a breadth. Such features can be defined as long, narrow regions of pixels that are, in general, of a different intensity than the background.

Therefore, in this kind of application where feature detection is the only requirement, mapping of an image from the image space to feature space via the *Radon transform*, with subsequent processing in the feature space, is sufficient. One of the advantages of the Radon transform is that both the scale and orientation of the target pattern, in addition to its location, can be automatically determined. A great deal of research has been dedicated to developing Radon transform-based algorithms for linear feature detection, and specifically for ship wake detection in SAR images [3], [4]. Since a Radon algorithm accumulates image amplitudes without adjusting for the background level, variable background levels can cause problems: bright regions can give rise to false detections, and internal waves in dim regions may not be well detected. Thus, a method based on a localization of the Radon transform has been introduced to improve the detection of internal wave features that are significantly shorter than the image dimensions or that display some curvature [4]. Preprocessing and postprocessing on the Radon transformed data to exploit this fact produced very good internal wave detection with almost no false alarms.

2 INTERNAL WAVES ON SAR IMAGES

Internal waves become visible on radar images because they are associated with variable surface currents which modify the surface roughness patterns via current-wave interaction. The radar is a surface sensor: the higher the roughness, the higher is the radar return and the brighter is the image in intensity. Internal wave forms are associated with rough and smooth bands and show up bright and dark bands in the image [5].

3 RADON TRANSFORM

3.1 Definition of the Radon Transform

The Radon transform of a two-dimensional Euclidean space (continuous image) is defined as

$$\check{f}(\rho,\theta) = \int_D \int f(x,y)\delta(\rho - xcos\theta - ysin\theta)dydx \quad (1)$$

where D is the entire x-y image plane, $f(x,y)$ is the image intensity (gray level) at position (x,y), δ is the Dirac delta function, ρ is the length of the normal from the origin to the straight line, and θ is the angle between the normal and the x-axis [6]. The Radon transform accentuates straight-line features in an image by integrating image intensity along all possible lines in the image space. The presence of the Dirac delta function forces the integration of $f(x,y)$ along a line whose normal representation is $\rho = x\cos\theta + y\sin\theta$.

3.2 Radon Transform Drawbacks

There are some drawbacks to using the Radon transform for internal wave detection. Since the intensity integration is performed over the entire length of the SAR image, it can have difficulty detecting line segments which are significantly shorter than the image dimensions. It also has no capability of providing information about the positions of the end-points of these shorter line segments, or on line length. And internal wave features that span across the entire image but display some curvature may not produce suitable peaks or troughs in the transform domain. Therefore, an adaptation of the Radon transform is necessary to enhance the internal wave feature detection in presence of these kind of problems. Thus, we have adapted the Radon transform so as to localize the area in which each integration takes place. This will reduce the problem of the detection of internal wave features that are much shorter than the image dimensions, and that display some curvature.

3.3 Localized Radon Transform

The localized Radon transform can be represented as the original transform (1) with limits on the integration, and with an additional parameter σ as follows:

$$\begin{aligned}\check{f}(\rho,\theta,\sigma) = & \int_{x_{min}}^{x_{max}} \int_{y_{min}}^{y_{max}} f(x,y) \\ & \cdot\delta(\rho - xcos\theta - ysin\theta)dydx\end{aligned} \quad (2)$$

where

- $x_{min} = min(\rho\cos\theta - \sigma\sin\theta, \rho\sin\theta - (\sigma+\lambda)\sin\theta)$,
- $x_{max} = max(\rho\cos\theta - \sigma\sin\theta, \rho\sin\theta - (\sigma+\lambda)\sin\theta)$,
- $y_{min} = \rho\sin\theta + \sigma\cos\theta$,
- $y_{max} = \rho\sin\theta + (\sigma+\lambda)\cos\theta$,

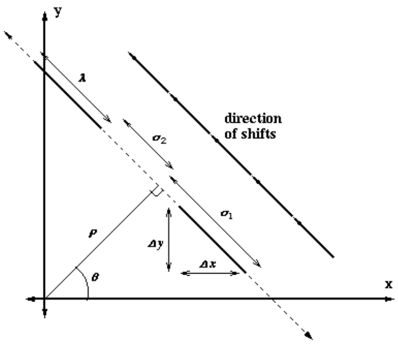


Figure 1: Illustration of shifting the LSOI. In this case, the positive shift direction is up and to the left, corresponding to an increasing σ.

- σ is a shift parameter, and
- λ is the length of the line segment of integration (LSOI).

The additional parameter σ creates a transform space that is now three-dimensional. σ represents the point along the line represented by θ and ρ where the integration begins, or the distance the LSOI has been shifted along the line. λ is simply the length of the LSOI. Fig. 1 illustrates this idea. Reference [4] presents more discussion of the relative benefits of localizing the intensity integration in the Radon transform, as well as discussion of how the localized Radon transform is computed.

4 DETECTION ALGORITHM

The procedures and stages involved in the problem of detection and orientation of internal wave features from SAR images are illustrated in Fig. 2. The major steps are as follows:

- *Preprocessing:* For the majority of SAR images, it is important to apply a filter to the image to smooth it and remove most of the noise. If this were not done, problems of isolating individual lineaments would occur later in the analysis. In this study a 3 x 3 median filter is applied to the SAR data.
- *Algorithm Decision:* This is a very important stage since it decides whether to apply the original Radon transform or the localized Radon transform. It is based in an *a priori* internal wave knowledge of the SAR image situation. This *a priori* knowledge is given by a previous work on internal wave packet detection and location given in [1]. The size of the window which is extracted from the original SAR image is quite important as the Radon transform will be most efficient when the size of the window is about the size of the internal wave packet.
- *Radon Transformation:* Then, the Radon transform or the localized Radon transform are performed on the filtered SAR data. This results in the production of accumulator arrays (positive ρ and negative ρ) in the parameter space where brighter tones represent higher counts in the accumulator arrays (see Fig. 3). Next,

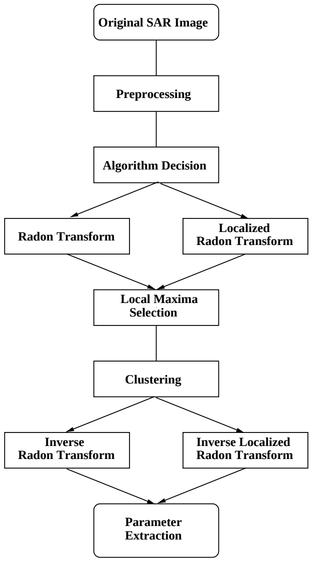


Figure 2: Flowchart for internal wave feature detection and orientation.

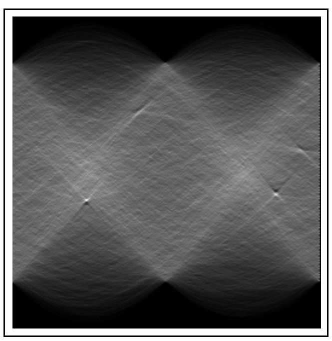


Figure 3: Radon transform of the synthetic noisy image shown in Fig. 4(a).

a local maxima thresholding method is applied to the Radon space to obtain the brightest n points.

• *Clustering:* This stage decreases spurious false detections and chooses a single line to represent each individual internal wave feature (a thick-line feature, such as internal waves, produce multiple, clustered, high-intensity points in the Radon space). Points within a given distance $(\partial\rho, \partial\theta)$ of each other are assigned to the same cluster. Clusters with fewer than m points are discarded. The peak point within each remaining cluster is chosen to represent the feature. When the peak value in a cluster is shared by more than one point in the cluster, the point maximum in the centroid of the cluster is used [7]. This procedure provides the best estimate of the center line of internal wave features.

• *Parameter Estimation:* The information provided by the Radon transform (line orientation (θ) and distance (ρ)), can be very useful for the characterization of the detected internal wave features. From here, very important internal wave parameters, i.e. the internal wave packet orientation and wavelength, can be estimated.

5 RESULTS AND DISCUSSION

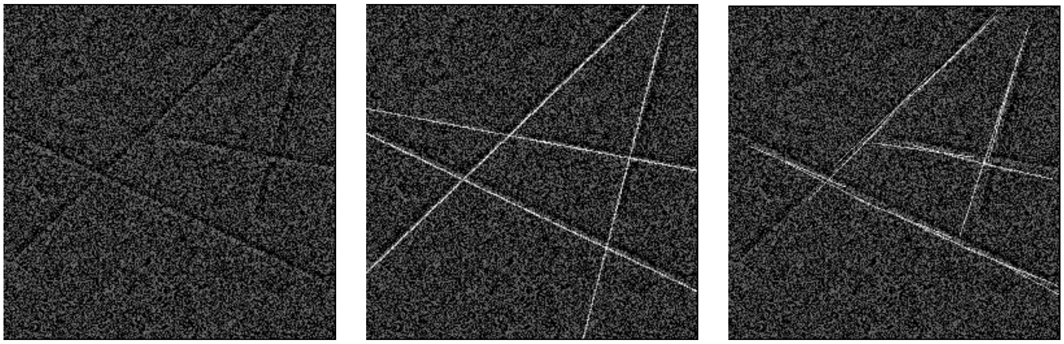
We have tested the performance of the described internal wave detection and orientation algorithm on a set of synthetic images and real ERS-1 SAR images. It was desired to test the algorithm's robustness to detect both bright and dark internal wave features, both straight and curved features, and multiple features in images containing multiplicative (speckle) noise.

Fig. 4(a) shows a 256 x 256 synthetic image which has been corrupted by a multiplicative Weibull noise. The Weibull probability distribution is a generic model for radar noise that has been demonstrated to provide a good approximation under many different imaging conditions [4]. The synthetic noise was created using as scale and shape parameters: $\alpha = 1.1$ and $\beta = 0.7$. The image contains several bright and dark lines: 2 lines extending to the image dimensions, and 2 lines much shorter than the image dimensions. Fig. 4(b) shows the results obtained by applying the Radon transform approach. It can be seen that the method detects well the 4 lines, although we do not have any information about the end-points of the lines. Thus, we have applied the localized Radon transform to the same image to show up the advantages of such approach. Fig. 4(c) shows the detected lines from the localization of the Radon transform. It can be seen that the 4 lines have been well detected, as well as the accuracy of the information about the end-points of the detected lines.

Fig. 5(a) shows a 360 x 360 ERS-1 SAR image containing quasi-linear internal wave features. Under this type of image, when the internal wave features of interest are approximately the same size as the image dimensions, as the SAR image dimensions, the simple Radon transform usually performs quite well. From the image, we can see that almost all the internal wave crests have been detected, although the probability of detection tends to be reduced, particularly for short features located near the edge of the image. Fig. 5(b) shows a 400 x 400 ERS-1 SAR image containing an internal wave packet which displays some curvature. The localized Radon transform has then been applied to detect these circular features and also to detect the end-points. From the image, we can see that the main crests are succesfully detected and orientated.

6 CONCLUSIONS

This paper has presented the possibility of semi-automatic detection and orientation of internal wave features from SAR images by applying Radon transform methods to the area of where the internal wave packet was detected. The success of the algorithm was found to depend greatly upon the internal wave and the image appearances. Nevertheless, this is an initial approach for the understanding of internal wave feature orientation from satellite data, and more work and study are required to fully interpret these results.



(a) (b) (c)

Figure 4: (a) 256 x 256 synthetic noisy image. (b) Radon tranform detection. (c) Localized Radon transform detection.

ACKNOWLEGMENTS

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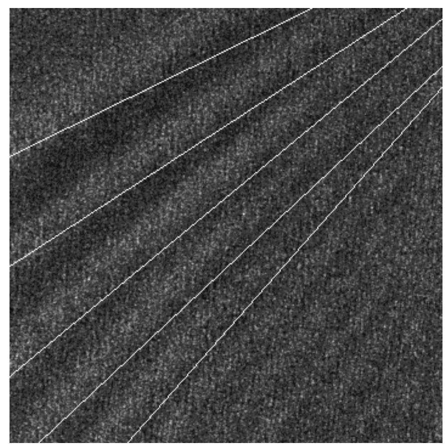
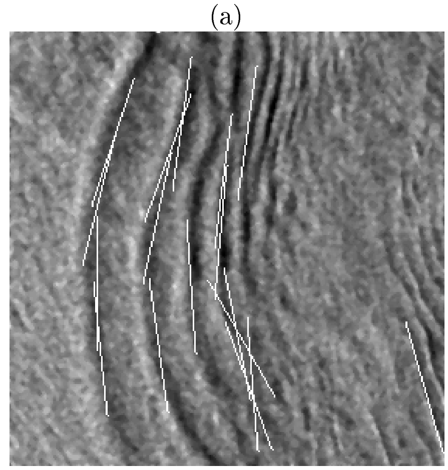


(a)



(b)

Figure 5: (a) Radon transform detection in an ERS-1 SAR image. Mainly 5 internal wave crests are detected and orientated. From the distances of the detected lines we can estimate that the internal wave packet is propagating northwest. (b) Localized Radon transform detection in an ERS-1 SAR image. Mainly 4 curvilinear internal wave crests are well detected and localized. They also show the radius of curvature and the direction of the internal wave packet.