The Use of Edge-Enhancing Smoothing Pre-Filters to Aid in the Detection of Oceanic Features

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Abstract – Sea Surface Temperature (SST) images obtained by satellites, such as AVHRR, are used to detect turbulent oceanic pattern flows. Pre-processing techniques (filters) are used to remove possible noise contamination from the obtained images and improve oceanic feature detection. In this paper, we present how image pre-processing techniques based on the use of edge-enhancing smoothing nonlinear filters improve the detection of oceanic features by enhancing diffuse edges and removing scattered clouds present in SST imagery.

Key-words – Thermal imagery, AVHRR, edge detection, nonlinear filters, oceanic feature detection.

1. Introduction

Advanced Very High Resolution Radiometer (AVHRR) thermal images are used to study ocean dynamics, and specially to track and identify many oceanic features that trace turbulent flow patterns, resulting from the interaction of water masses of contrasting sea surface temperatures (SST). They are often called mesoscale features, because they exist on spatial scales of 50 to 300 km [1]. Some of these features can be detected with more ease than others, depending on the image resolution and atmospheric conditions but, in many cases, the contrast and geometrical characteristics of the turbulent flow patterns are the keys to successful detection.

The difficulty with thermal satellite images is that sometimes oceanic features cannot be easily detected, because many detection algorithms or techniques encounter some obstacles that decrease their performance. Cloud cover is one of them. Although clouds have often temperatures colder than ocean SST, their edges are very diffuse, they cover large spatial areas, they are always present in most thermal images, and they keep moving and changing shape continuously. This makes the tracking of some oceanic features a very difficult task. Image noise is another problem. No matter the resolution of the detected image, satellite detectors have inherent noise corruption in some bands, and the thermal band is no exception. Noise can affect specially in the masking of cloud cover, because cloud edges are generally very diffuse, and the difference between these diffuse edges and the water masses below is reduced by noise. These problems degrade the performance of many image processing techniques, like edge detection and image segmentation, to obtain accurate results. Noise that appears in thermal images is a consequence of satellite sensor effects, the amount of the water vapor present in the air and other atmospheric effects like diffusion, absorption, etc. Therefore, pre-processing techniques used to eliminate cloud and noise effects should improve the performance of spatial feature detection algorithms.

Smoothing the image is one way to reduce the effect of noise in edge detection and segmentation algorithms. Nonlinear filtering methods are capable of smoothing areas and at the same time edge-enhance their contours. These methods can be used as helping tools in the detection of features, and many of them have different tuning parameters that allow for the control of the final effect on the image.

2. Preprocessing filters

The most simple of all smoothing filters is the *Median* filter [2]. A vector or window (depending if we are talking in one or two-dimensional coordinates) of length N, where N is odd, is spanned through the whole image in search of the median values that the vector will obtain every time it advances. This method works well when spot noise is present in the image, but its smoothing characteristics are too strong. If the image has important information contained in fine detail, , like sharp edges or thin curved areas, this method could remove it.

The *Weighted Majority of samples and Minimum Range* (WMMR) filter [3] is another possibility among the available filters. In addition to its smoothing effect, this one also has edge enhancing capabilities. Its output is given by:

$$y = F_{WMMR}(x) = \sum_{j=i}^{(N-1)/2+i} w_j x_{(j)}$$

here, some value i, ranked somewhere in the N-length vector, should be found such that the value of x((N-1)/2+$_i$) - x($_i$) is a minimum. The variable x is the vector and the values in parentheses are the ranked positions of the values within the vector in ascending order. This ranking is used to simulate the process used by the median filter to choose its output, but instead allowing the function to obtain a value by the stated equation. It is suggested in [3] that for edge enhancement a useful choice as a weight can be:

$$w_j = \begin{cases} 1 & if \quad j = (N-1)/4 + i \\ 0 & otherwise \end{cases}$$

That will make the filter take the median of the (N+1)/2 closest samples. This filter will have good noise suppression, but also tends to smooth out signal detail.

Another nonlinear filter with sharpening characteristics is the *Comparison and Selection* (CS) filter [7]. To have sharpening characteristics, this filter outputs samples away from the median:

$$y = F_{CS}(x) = \begin{cases} x_{(j)} & if \quad \mu \geq x_{((N+1)/2)} \\ x_{(N-j+1)} & otherwise \end{cases}$$

here μ is the sample mean estimate of the vector $\boldsymbol{x}$, and $1 \leq j \leq$ (N+1)/2, and j is a tuning parameter that provides for different levels of enhancement. For example, if we select j= (N+1)/2, the output of the filter will be the median of $\boldsymbol{x}$. This filter sometimes tends to distort or remove small image features, but it uses the advantages of ranking its vector components to suppress the noise information that goes to the extremes.

The third filter studies is the *Lower-Upper-Middle* (LUM) filter [7] whose output is given by:

$$y = F_{LUM}(x) = \begin{cases} x_{(k)} \; if \; x_{(N+1)/2} < x_{(k)} \\ x_{(l)} \; if \; x_{(l)} < x_{(N+1)/2} \leq t_l \\ x_{(N-l+1)} if \; t_l < x_{(N+1)/2} < x_{(N-l+1)} \\ x_{(N-k+1)} if \; x_{(N-k+1)} < x_{(N+1)/2} \\ x_{(N+1)/2} otherwise \end{cases}$$

Two variables are used as tuning parameters, l and k, with $1 \leq k \leq l$ (N+1)/2. Parameter k is used for the smoothing effect, while l is used for the edge enhancing effect. The value of t_l is the midpoint between x(l) and x(N-l+1). If l is kept at its maximum and k is varied, the filter acts as a smoothing filter. If k is kept at is minimum and l is varied, the filter acts as a sharpener. When $1 < k \leq l <$ (N+1)/2, both sharpening and outlier rejection can be achieved at once. That is a desirable effect in our case.

Rank Conditioned Rank-Selection (RCRS) filters [4] are among the most complex ones, because they can be constructed using the properties of other filters with additional modifications, or a combination of them. For example, one possible RCSR filter can be constructed by modifying the selection criteria that the LUM filter uses. In this case, another independent tuning factor was added in the form of an *alpha-trimmed* filter [5]. The alpha-trimmed filter is similar to a median filter, but this time its selection criterion depends on having a vector size equal in length or smaller than the size of the vector being analyzed by the LUM filter. The mean obtained for the alpha-trimmed filter was used instead of the tl parameter in the LUM filter. This will produce different results that can be compared to the ones that would be obtained by using the filter before the tl parameter modification.

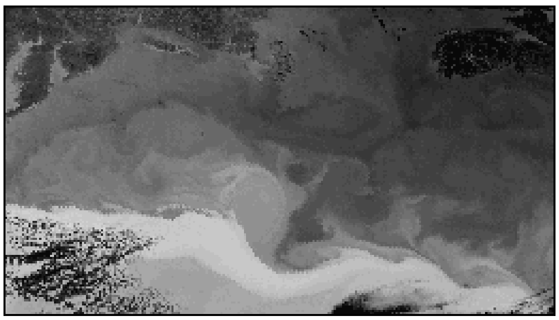

Fig. 1: AVHRR SST test image.

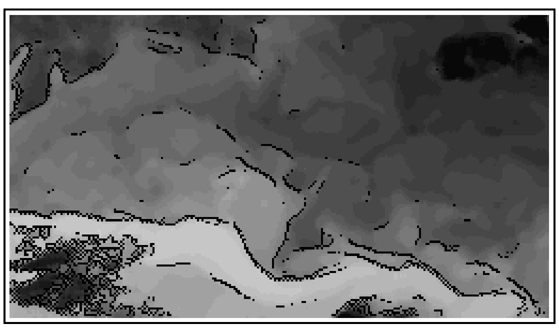

Fig. 2: Filtered image using the Median filter.

3. Results

The performance of the filters was studied using a 257 X 145 SST image of the Gulf Stream in the North Atlantic, shown in Figure 1. Continental mainland is present in both the upper left and upper right corners of the image, while scattered cloud cover appears in the lower left corner. The rest of the image corresponds to the ocean surface and some oceanic features can be clearly seen. For example, the Gulf Stream can be identified because it has a warmer SST (lighter gray level) temperature than surrounding water masses. This is an example of how feature characteristics establish in some manner the way that their edges will appear, or at least, the contours that they are supposed to have. The accurate identification of edges that are part *only* of oceanic features is the goal of this work.

The results obtained for each filter were compared using a simple edge detection method based on temperature gradients. The median filter results appear in Figure 2. This filter has strong smoothing effects, and much detail was lost while few important edges were detected. The results for the CS filter are shown in Figure 3. It can be seen that scattered cloud cover is reduced not so heavily as with the Median filter, and better and more continuous edges are found for most of the features present in the image.

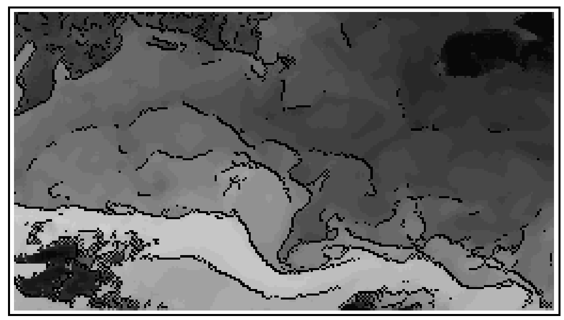

Fig. 3: Filtered image using the CS filter.

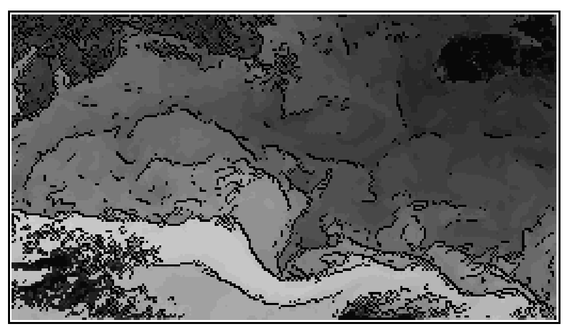

Fig. 4: Filtered image using the LUM filter.

Figure 4 shows the results for the LUM filter. Although this filter has two parameters for edge-enhancing and smoothing tuning, it did not reduce scattered cloud cover as well as the CS filter did. The detected edges are not as well defined as with the CS filter, and some scattered spots are generated as a result of the edge detection method that does not appear in the CS filter results. The results for the WMMR filter are shown in Figure 5. These results were good, but not better than the CS filter results. The WMMR filter generated less scattered pixels resulting from the edge detection than the LUM filter, but feature edges and scattered cloud cover reduction were better for the CS than for the WMMR filter. Finally, the results for the RCRS filter shown in Figure 6 did not detect acceptable feature edges in most of the image, and cloud cover was not reduced as well as with the other filters.

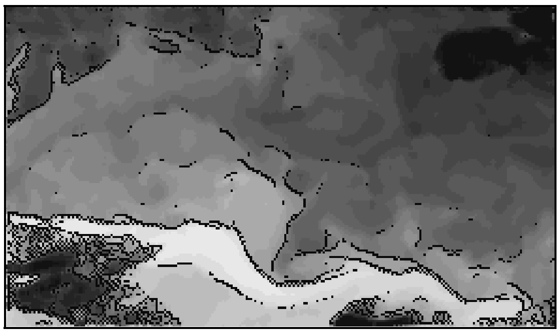

Fig. 5: Filtered image using the WMMR filter.

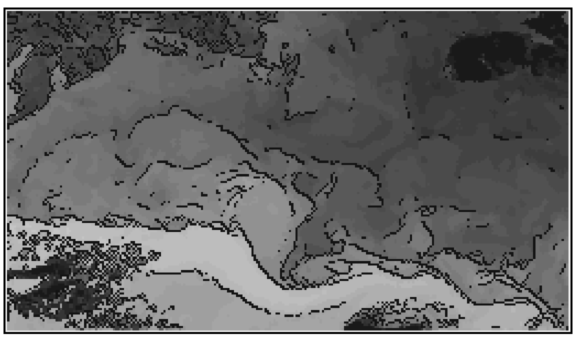

Fig. 6: Filtered image using the RCRS filter.

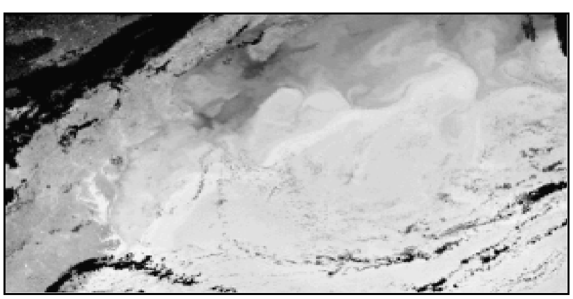

Fig. 7: North Atlantic SST image.

It is desirable that only feature edge detection and scattered cloud cover removal should be achieved, or at least, that both should be the dominant results to be obtained for our tests. Many alternatives were tested with a variety of parameter settings, and with window sizes of 3x3 and 5x5. Based on that criterion and according to the obtained results, the CS filter resulted in the best alternative. To illustrate the filter performance, a 490x461 SST image of the North Atlantic, shown in Figure 7, will be studied. The results obtained after the CS filtering process appear in Figure 8.

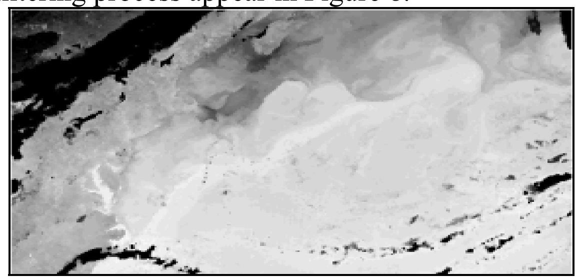

Fig. 8: Filtered North Atlantic SST image using the CS filter.

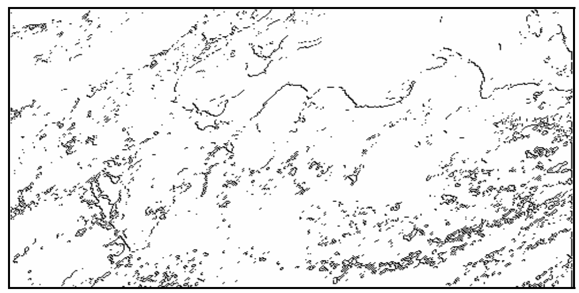

Fig. 9: Results of edge detection.

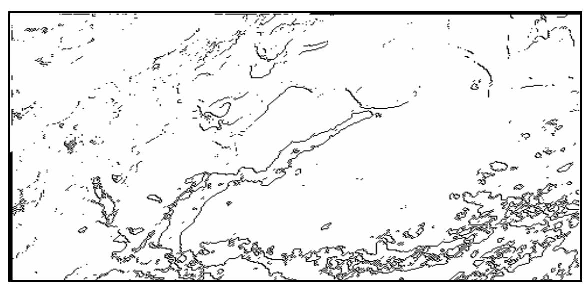

Fig. 10: Results of edge detection after CS filtering.

The results of edge detection based on temperature gradients applied to Figure 7 are shown in Figure 9. Although much detail is lost when using a window size of 5x5, most of the information concerning some of the features is kept, and much of the scattered cloud cover is eliminated. The results obtained for the CS filtered image are shown in Figure 10. Part of the north wall of the Gulf Stream is identified, but the most important feature detected is the Gulf Stream current. According to the range of temperatures used in these images, the Gulf Stream was a 29 degrees Celsius current.

The results shown here were the best obtained from a variety of tests, including different gray level thresholds, or using a smaller window size. In some cases, many edges that were detected did not have relation with the desired features. Other cases did not have complete contours, and the stream appeared with some incomplete borders. That implies that the results of any tested method should be always checked to verify that satisfactory results are obtained, according to the characteristics that the different features should present.

4. Conclusion

Here we have presented results that show how nonlinear filtering techniques such as the CS filtering can be of much help in the detection of oceanic features. Although the edge detection method that was used in this tests works only by identifying temperature differences according to specific given values, both images demonstrate that different features can be detected if the methods provide for tuning variables or other types of control. Even using very simple methods, satisfactory results can be obtained when specific features are to be detected.

Nevertheless, these results apply only for images showing enough ocean surface free of dense cloud cover, similar to Figures 1 and 7, because the temperature values that are used as parameters must be changed if different conditions are present in other images. Temperature-based methods alone will not be effective for all kind of thermal oceanic images, especially if we want these detections to be made in an automatic manner. Feature characteristics, especially shape, must be considered as critical information for successful feature detection, because most of these features are identified according to their contours, and can be tracked even if the feature temperature varies with time [6].

5. Acknowledgments

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