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Satellite image processing for oceanic applications using fuzzy logic

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Abstract: In this paper, we have performed a comparative analysis of various conventional contrast enhancement techniques (histogram equalisation and adaptive histogram equalisation), the recent fast grey-level grouping method (Chen et al., 2006a,b), the fuzzy logic method (Hanmandlu and Jha, 2006) and a modified fuzzy logic method (Nair et al., in press) to find out which of these is well suited for automatic contrast enhancement for satellite images of the ocean, obtained from a variety of sensors. The principle of transforming the skewed histogram of the original image into a uniform histogram is used as the basis for all techniques. The performance of the different contrast enhancement algorithms is evaluated based on the visual quality and the Tenengrad criterion. The inter-comparison of different techniques was carried out on a standard low contrast image and also on different satellite images with different characteristics. Based on our study, we conclude that the modified fuzzy logic (Nair et al., in press) is well suited for automatic contrast enhancement of satellite images of the ocean.

Keywords: contrast enhancement; GLG; grey-level grouping; histogram; satellite images; fuzzy; entropy.

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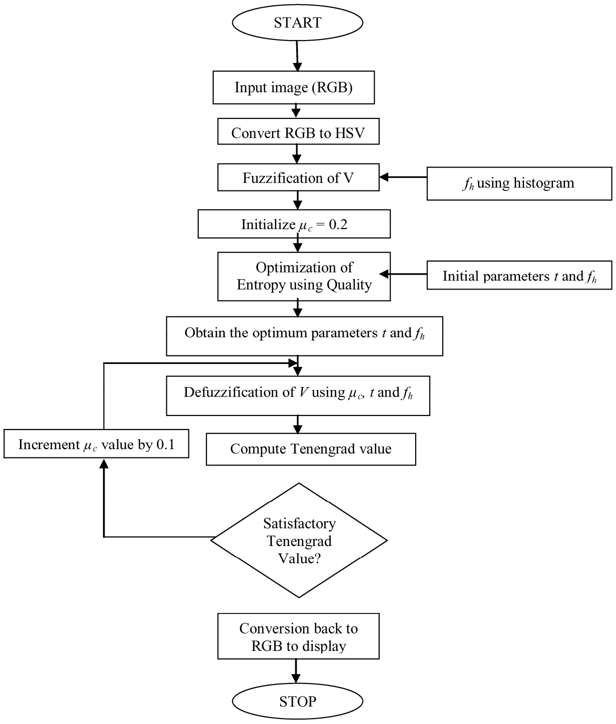
1 Introduction

Automatic enhancement of features in images from satellite sensors is crucial from an operational perspective, as voluminous data are required to be processed in the shortest possible time (Gonzalez and Woods, 2002). Among the various features present in an image, the grey levels, their joint probability distributions and spatial distributions characterise spatial features of an object (Blackwell, 1946). In oceanic images, the spatial features are the signatures left by natural changes (like the changing wind pattern) or by some moving platform (like ship). A problem of fundamental importance in ocean image analysis is extraction of these signatures efficiently and quickly.

Given the plethora of algorithms available for image contrast enhancement, the impetus for the present study was to identify which of the existing contrast enhancement algorithm is the most suitable algorithm for use with satellite images from a cross section of satellite sensors having varying characteristics (Hanmandlu et al., 1997; Kim, 1997; Lakshmanan et al., 2008; Pal and King, 1981; Russo and Ramponi, 1995). The impetus for this study, therefore, was to evaluate the various histogram-based algorithms available for contrast enhancement to arrive at an optimal algorithm, which is capable of extracting the spatial features from such low contrast images. In this study, we applied the various methods for contrast enhancement, i.e. standard histogram equalisation, adaptive histogram equalisation, fast grey level grouping (GLG) method (Chen et al., 2006a,b), fuzzy logic method (Hanmandlu and Jha, 2006) and a modified version of the fuzzy logic method advocated by us (Figure 1) (Nair et al., in press) on typical low contrast satellite images of the ocean, obtained from different sensors.

Figure 1 Flow chart of modified fuzzy logic method as suggested and implemented in this study



As we were interested in inter-comparison of the conventional contrast enhancement techniques with the recent GLG and fuzzy-based techniques on low contrast images; and as there are no standard low oceanic images available, we initially applied all the techniques on a low contrast 'standard' grey scale image pertaining to the picture of a '*Mineral*' image taken from the image processing package IDL (Choi and Krishnapuram, 1997) (version 6.3).

2 Performance measures

The quality of an image is traditionally measured by objectively computing the sharpness of the image. Statistical sharpness measures were developed based on various categories: gradient-based, variance-based, correlation-based, histogram-based and frequency domain-based methods (Krotkov, 1989; Santos et al., 1997). Sharp images usually involve scattered grey levels in a large dynamic range, suggesting a large variance. Elimination of noise and computational complexity of the algorithm are the two primary concerns. Gradient-based sharpness measures, especially the Tenengrad measure, are known for their effectiveness and low computations. Moreover, their pixel-based computations facilitate the differentiation between edge and noise pixels. Therefore, to evaluate the efficacy of a particular method against existing contrast enhancement techniques, the most well-known benchmark image sharpness measure, the Tenengrad criterion is used to compare the results of contrast enhancement methods. The Tenengrad criterion is based on gradient magnitude maximisation, and it is considered one of the most robust and functionally accurate image quality measures. The Tenengrad value of an image, I is calculated from the gradient $\nabla I(x,y)$ at each pixel (x, y), where the partial derivatives are obtained by a high-pass filter, e.g. the Sobel operator, with the convolution kernels i_x and i_y. The gradient magnitude is given as

$$S(x,y) = \sqrt{\left(i_x \otimes I(x,y)\right)^2 + \left(i_y \otimes I(x,y)\right)^2}$$

and the Tenengrad criterion is formulated as

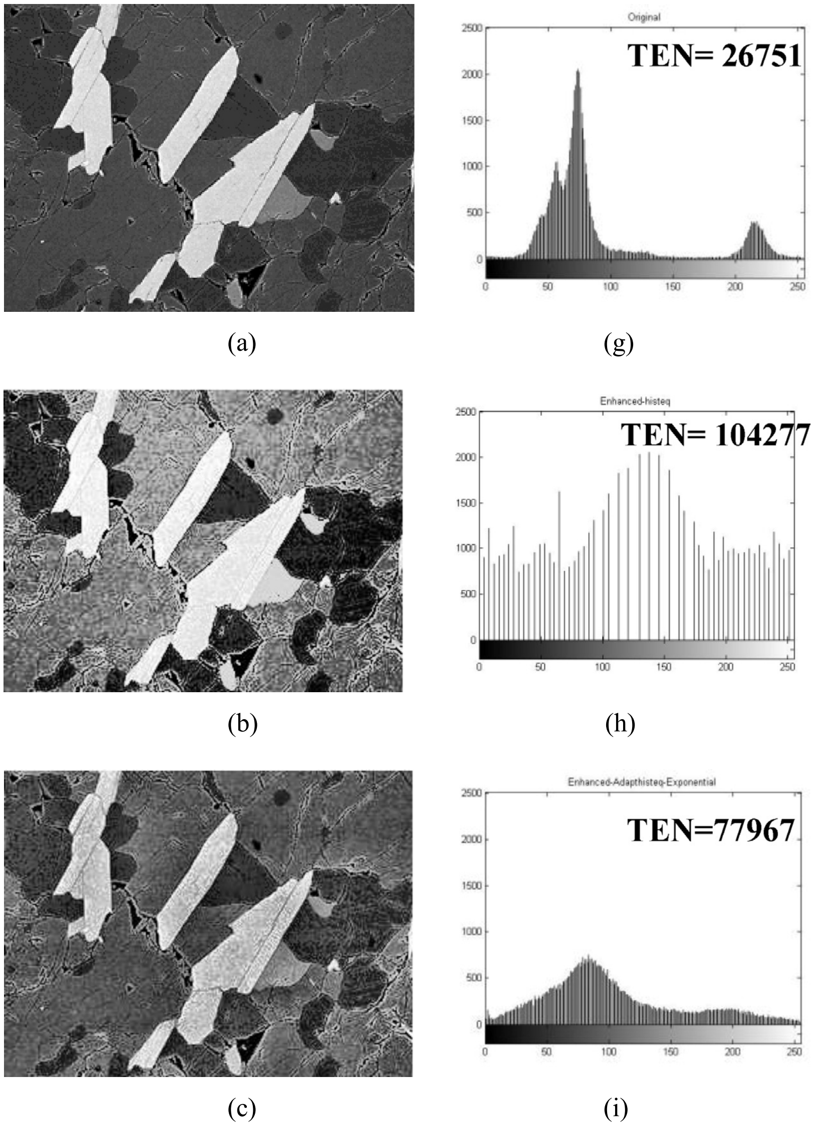
$$\text{TEN} = \sum_x \sum_y S(x,y)^2 \quad \text{for } S(x,y) > T$$

where T is a threshold. The image quality is usually considered higher if its Tenengrad value is larger. However, for some images, even though Tenengrad value for histogram equalisation is larger visual degradation can occur due to enhancement of noise also.

3 Comparative analysis

From the results of contrast enhancement on the original along with their respective histogram distributions and Tenengrad values for the various methods compared (Figures 2 and 3), it became apparent that the modified fuzzy-based technique yielded better results for automated contrast enhancement.

Figure 2 (a) Represents the original image of size 216 × 288, (b)–(f) represents the enhanced images of Mineral image after applying the histogram equalisation, adaptive histogram equalisation with exponential distribution, GLG, fuzzy method (Hanmandlu and Jha, 2006) (with optimal μ_c value = 0.32) and the modified fuzzy methods (with optimal μ_c value = 0.36), respectively and (g)–(l) represents the corresponding histograms, respectively



(a) (g)

(b) (h)

(c) (i)

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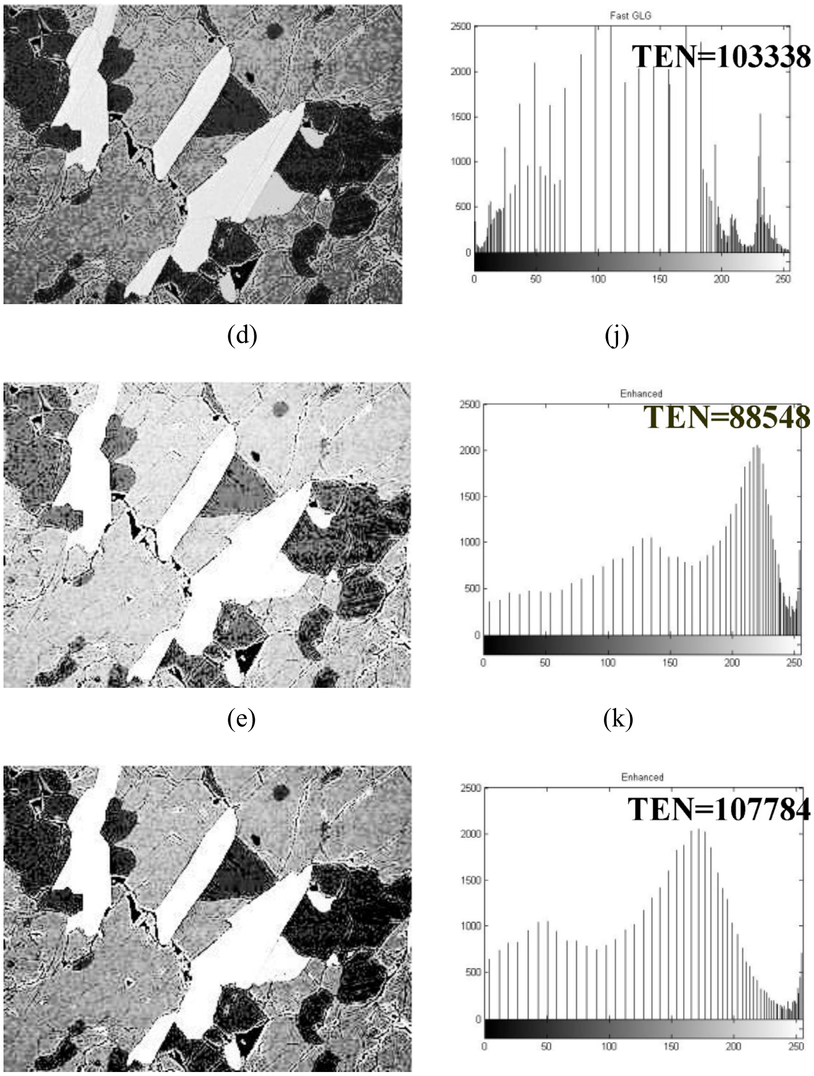


(d) (j)

(e) (k)

(f) (l)

Note: Tenengrad values are shown in the top right corner of each image. As can be seen from the Tenengrad values, the visual quality is best for the modified fuzzy-based method with an improvement of 22% as compared to the fuzzy method of Hanmandlu and Jha (2006) and 5% as compared to the fast GLG method.

Figure 3 Plot of the Tenengrad values obtained after applying the fuzzy logic method on a standard low contrast 'Mineral' image with different crossover point (μ_c) values

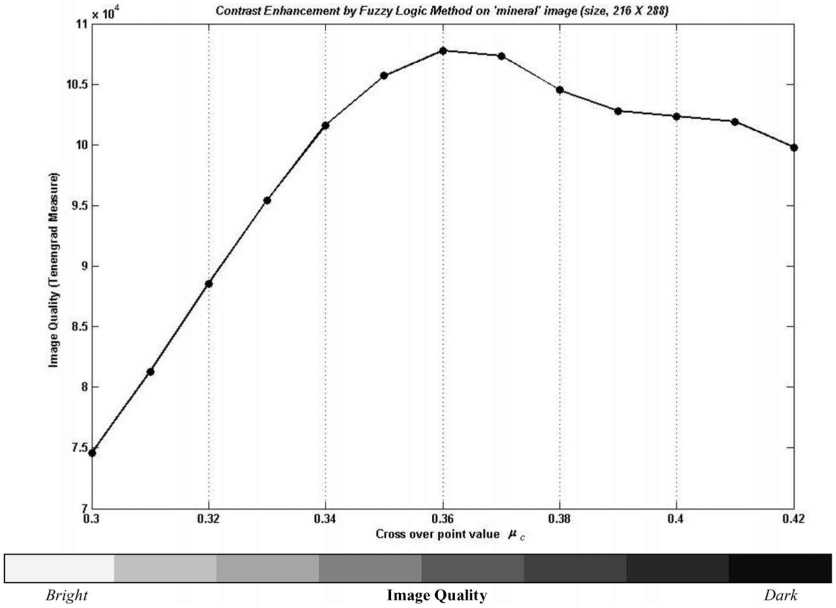
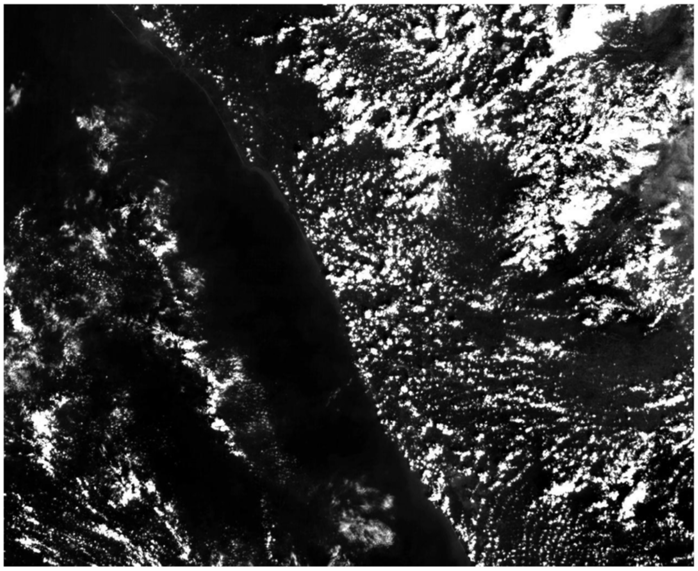


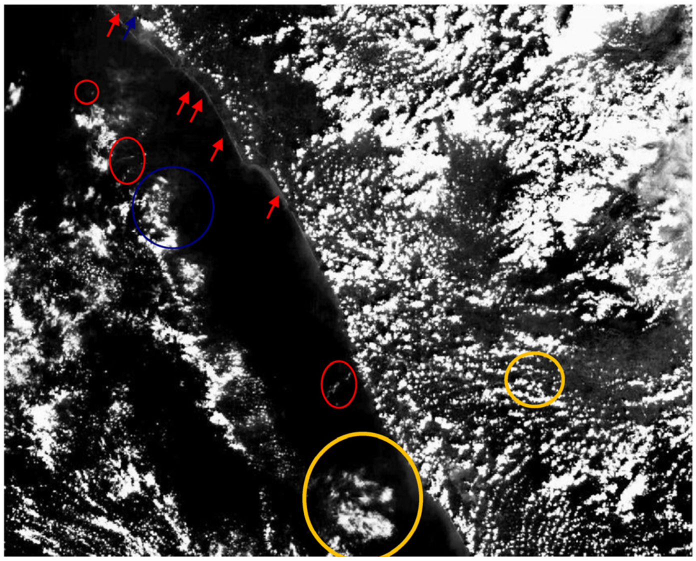
Figure 4(a) shows the original low contrast sub-image from IRS P4 OCM satellite sensor with a medium resolution. The image pertains to the west coast of India and is predominantly covered by clouds making visual interpretation very difficult, as most of the features remain invisible. This is a typical image due to environmental degradation and is very common for most seasons of the year. The image looks under exposed with low signal to noise ratio (noise assumed here is cloud cover). As such images are most common from optical satellite sensors, the utility of extraction of features from such images becomes very important. Figure 4(b) shows the results of the automatic contrast enhancement using the modified fuzzy logic method, indicating a visual quality improvement and also an increase in the Tenengrad value by 23%. As explained in the figure caption many important features of the image can now be discerned enabling more meaningful information extraction.

Ship detection by SAR has become a very important endeavour in the past few years and numerous algorithms to assist in identification have been developed. The appearance of ship or ship wakes in radar images depends on various parameters: the shape of the platform, the sea state, the observation geometry and the characteristics of the radar, like the carrier frequency, the polarisation and the observation configuration. Depending on the configuration, one or several of the following features are visible. First, the wake is nearly always characterised by a dark streak behind ships in SAR images. This dark trail originates from the turbulent vortex created by the ship, which reduces the roughness of the sea. The linear features are of primary importance when wake detection is considered, because they allow for the use of line detection algorithms. However, the detection task is complicated by the presence of multiplicative noise (speckle), which is prominent when the sea state is high, since it hides the features to be extracted (i.e. the wake and/or the ship).

Figure 4 (a) and (b) Represents the original and fuzzy logic-based (μ_c value = 0.4) enhanced images of low contrast Satellite Image I, respectively (see online version for colours)



(a)



(b)

Note: Features that have become evident after contrast enhancement are (1) shoreline and beach (represented by red arrows), (2) ships at sea (represented by red circles, the second red circle from the left also shows the wake of the moving ship), (3) cloud cover over sea (represented by yellow circle) and (4) part of a road (represented by smaller yellow circle on the land). The quality of the image (Tenengrad value) improved by 23% with a computation time of ~8 sec on the original satellite sub-image of size 940 × 1,267. The satellite sensor was IRS 1C pan CCD. The image was of the west coast of India.

Most of the algorithms used begin with the Radon transform, since its properties make it particularly suitable to line detection in speckle noise. The Radon transform is applied to the raw and noisy image, and the features visibility is then optimised by using subsequent processing methods, such as Wiener filtering. Other approaches rely on multi-scale analysis, such as the wavelet transforms, which enable in extracting features by assuming that objects, such as wakes display a certain correlation between adjacent scales, unlike noise. Another approach may be to use the Hough transform, which is related to the Radon transform in its principle and can be faster to compute, but which is not as robust to noise; and the approach requires despeckling the image beforehand. SAR is useful in ship detection on development of sophisticated algorithms for image analysis and information that can be extracted from SAR includes location of ships, their speed, heading and sometimes their size class and approximate type.

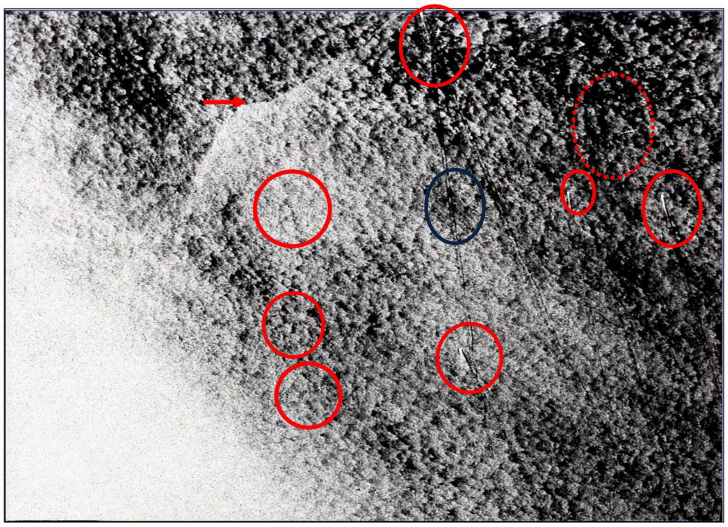
In recent years, however, to preserve the full resolution and extract information regarding smaller areas of interest, SAR speckle in marine single look complex images is investigated by means of a physically consistent model (Migliaccio et al., 2007), with the belief that marine speckle contains information that can be exploited once an appropriate physical model is established, thus helping in the detection of small dark areas (oil spill) and small dominant scatterers (ships). Against this background, we wished to see whether a simple contrast enhancement of a SAR or an optical image can result in any incremental improvement of the visual quality (*and in speckle noise reduction*) vis-à-vis the ship (and/or wake) detection problem without resorting to any sophisticated algorithms and speckle modelling.

Figure 5(a) shows the raw sub-image of ERS 1 satellite SAR sensor with a medium spatial resolution. The image is covering the ocean in Gulf of Oman. The raw image is featureless with low contrast and partially noisy especially in the lower left corner of the image, an artifact of the sensing mechanism and the subsequent processing. Figure 5(b) shows the visually improved image where many features are discernible. The Tenengrad value has also considerably increased by 228%. Again, as explained in the figure many important features in the image can now be discerned enabling more meaningful information extraction. Figure 6(a) shows the original sub-image from a high-resolution optical satellite sensor, IKONOS. The image covers the Bay of Bengal region and the quality of the image is good. Figure 6(b) shows the contrast enhanced image with substantial improvement in visual quality as well as the Tenengrad measure by 22%. As explained in the figure many important features in the image can now be discerned enabling more meaningful information extraction.

Therefore, our study clearly indicates that the modified fuzzy logic method can be used for automatic contrast enhancement of low contrast satellite images from different sensors to extract meaningful information on features present in the images.

Figure 5 (a) and (b) Represents the original and fuzzy logic-based (optimal μ_c value = 0.4) enhanced images of low contrast Satellite Image II, respectively (see online version for colours)

(a)

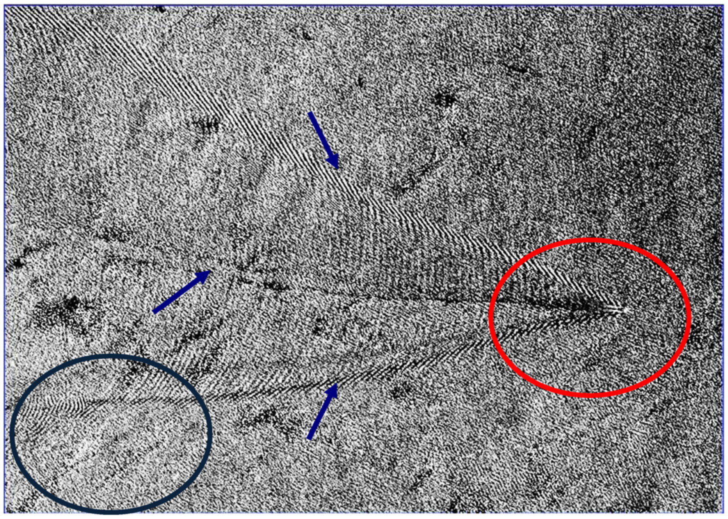


(b)

Note: Features that have become evident after contrast enhancement are (1) oceanic front (represented by red arrow), (2) ships at sea (represented by red circles), (3) the wake of the moving ship (represented by blue circle) and (4) an almost invisible ship with its wake (represented by dashed red circle).The quality of the image (Tenengrad value) improved by 228% with a computation time of ~6 sec on the original satellite sub-image of size 806 × 1,127. The satellite sensor was ERS SAR. The image was of the Gulf of Oman.

Figure 6 (a) and (b) Represents the original and fuzzy logic-based (μ_c value = 0.45) enhanced images of low contrast but high resolution Satellite Image III, respectively (see online version for colours)

(a)



(b)

Note: Features that have become more prominent after contrast enhancement are (1) the transverse waves and the turbulent stern wake in the lee side of the moving ship (represented by blue arrows), (2) small ship at sea (represented by red circles), (3) the clear Kelvin wake structure due to the moving ship (represented by blue circle), (4) an almost invisible ship with its wake (represented by dashed red circle) and (5) the divergent cusp waves (represented by the blue circle). The quality of the image (Tenengrad value) improved by 22% with a computation time of 5 sec on the original satellite sub-image of size 691 × 978. The satellite sensor was high resolution IKONOS Pan CCD. The image was of the east coast of India.

4 Conclusion

An inter-comparison of the conventional histogram-based contrast enhancement techniques (like histogram equalisation and adaptive histogram equalisation) along with the recent histogram-based GLG method (Chen et al., 2006a,b), the fuzzy logic method (Hanmandlu and Jha, 2006) and the modified fuzzy logic method as suggested in this paper was carried out to ascertain which of these methods is well suited for automatic contrast enhancement of satellite images of the ocean. The different methods were applied on a variety of oceanic images and it is concluded that the modified fuzzy logic method as elucidated in this paper has improved the visual quality, as well yielded a higher Tenengrad measure of quality.

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