An Algorithm for Pre-Processing of Satellite Images of Cyclone Clouds

Sreeparna Banerjee
Ishita Dutta
West Bengal University of Technology
BF-142 Sector I Salt Lake
Kolkata 700064, India
Sreeparna Banerjee
West Bengal University of Technology
BF-142 Sector I Salt Lake Kolkata 700064, India

Mallika De
University of Kalyani
Kalyani, India

ABSTRACT
Rapid advances in satellite imaging technologies have made it possible to obtain images of the atmosphere using different modalities and accordingly, make weather predictions. The progress of cyclone storms is one such area where cloud intensity images exhibit characteristic patterns at various stages of evolution. These patterns have been classified using Dvorak's technique, which is based on expert human judgment. Recent research efforts are being made to perform a computer analysis of these intensity patterns in order to make the classification process more objective. However, in order to perform an analysis of these image intensity patterns, the satellite images of different modalities need to be preprocessed to extract the dominant cyclone cloud patterns. This paper describes our algorithm to obtain cloud intensity contours to be used for pattern analysis. Results obtained using Visible (VIS) and Enhanced Infra-Red satellite images of cyclones have been found to be promising.

General Terms
Image Processing, Pattern Recognition

Keywords
Cyclone images, Visible images, Enhanced Infra-Red images, Dvorak Technique

1. INTRODUCTION
With the advances in satellite imaging technologies in the past few decades, it is possible to obtain images of remotely sensed objects such as cyclone cloud intensities. Such images are useful for weather prediction, particularly in forecasting cyclone storms. Images used for cyclones include visible (VIS) images obtained during the daytime and Enhanced Infra-Red (EIR) images which can be obtained over a 24 hour period.

Tropical Cyclone (TC) in the Indian Ocean and Bay of Bengal, or equivalently, a typhoon in the Pacific Ocean or a hurricane in the Atlantic Ocean is an area of low pressure with rotating and converging winds and ascending air with the central core being warmer than the surrounding atmosphere. The typical cyclone is characterized by a central eye surrounded by spiraling cloud bands of varying intensity. During different stages of its evolution, the cyclone has changing cloud intensity patterns, which have been classified with the help of T-numbers, using the Dvorak technique [1]. This technique, although widely used even today, is a manual technique relying on expert human judgment, and so, efforts are in progress to automate the technique.

Current satellite imaging technologies have resulted in cyclone images in the visible (VIS), enhanced infra-red (EIR) range as well as the mapping of water vapor content in images. EIR images can be obtained in the night and the Dvorak technique [2] has also been extended to accommodate EIR image classification. However, the images acquired need to be pre-processed as there might be smaller storm cloud formations, shear, Central Density Over cast (CDO) in addition to noise. The pre-processing stage also involve the identification of the dominant cyclone cloud (region of interest – ROI) and extraction of the ROI contours.

In this paper, we describe our efforts in pre-processing VIS and EIR cyclone cloud intensity patterns. Section describes earlier work. Our methodology is described in Section III followed by results and discussion in Section IV.

2. EARLIER WORK
One of the earliest efforts was that of Griffin et.al. [3] who tried extract cyclone contours and eye from radar scans of reflectivity patterns. Wood [4] have studied the Doppler velocity patterns from their radar scans. Lee and Lui [5] have used the Active Contour Model (ACM) to extract contours. Wong et.al. [6] have used radar reflectivity images which have been subsequently thresholded, contrast enhanced and the ROI extracted using motion estimation techniques. Liu [7]] has also used an ACM based technique for contour extraction. Zhang et.al. [8] also used the contour model to extract the cyclones. Pao [9] has used a region growing segmentation technique followed by image thresholding and slicing before typhoon image reconstruction is performed. Pineros et.al. [10] used long wavelength IR images in their study. They used a low pass filter to remove noise followed by application of Sobel template to compute the gradient of the brightness of temperatures, which were subsequently analyzed. Zhang and Hu have also used a histogram based technique [11] for segmentation.

3. METHODOLOGY
Satellite images of several cyclones /hurricanes/typhoons spanning over two decades have been used for the study. Of

these 252 images, 227 are EIR images and 15 are VIS images.

The preprocessing steps are as follows:

1. Thresholding
2. Noise Removal
3. Opening
4. Flood filling
5. Boundary extraction

The steps are briefly described below.

Thresholding

The thresholding is based on Otsu's method [10] described below.

Otsu's thresholding method is based on the idea that a threshold that minimizes the weighted within-class variance is to be found. This is the same as maximizing the between class variance. The method assumes that the histogram of pixel intensities is bimodal. The weighted in-class variance is given by

$$\sigma_w^2(t) = q_1(t)\sigma_1^2(t) + q_2(t)\sigma_2^2(t)$$

with the in-class probabilities being given by

$$q_1(t) = \sum_{i=1}^{t} P(i)$$

and

$$q_2(t) = \sum_{i=t+1}^{I} P(i)$$

and the class means are given by

$$\mu_1(t) = \sum_{i=1}^{t} \frac{iP(i)}{q_1(t)} \qquad \mu_2(t) = \sum_{i=t+1}^{I} \frac{iP(i)}{q_2(t)}$$

The individual class variances are

$$\sigma_1^2(t) = \sum_{i=1}^{t} [i - \mu_1(t)]^2 \frac{P(i)}{q_1(t)}$$

$$\sigma_2^2(t) = \sum_{i=t+1}^{I} [i - \mu_2(t)]^2 \frac{P(i)}{q_2(t)}$$

and

Noise Removal

Noise removal is performed using median filters

Opening

Following Guo et.al. [11] procedure for galaxy images, an opening and flood filling operation was performed on the cyclone images. Opening is a morphological operation defined by erosion followed by dilation and is given as

$$O(A, B) = A \circ B = D(E(A, B), B)$$

Flood Filling

By using a flood filling operation the ROI boundary can be obtained .

Table 1. Size of structuring elements

Operation	Size of Structuring Element	Intensity
Opening	60 pixels diameter	All values=1
Erosion	3 pixels diameter	All values=1

Boundary Extraction

The Freeman Chain code is used for boundary extraction. Freeman chain code is a 8-connected 3x3 windows based code. The chain code scheme is a representation of numbers that determines the direction of the next pixel relative to the present direction. This gives closed representation of the contour.

The flowchart for the process is given in Figure 1.

4. RESULTS

Input images comprising of Enhanced Infra-Red (EIR) and visible (VIS) images are first digitized and subsequently Otsu's method is applied to threshold the images. This method is applied for automatic binarization level decision, based on the shape of the

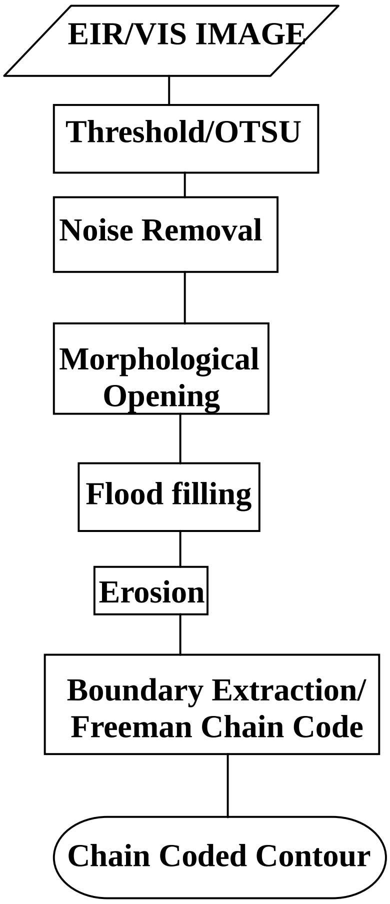

Fig. 1: Flowchart for preprocessing cyclone images

element to an input image and creating an output image of the same size. Figures 2(a-c) show images of hurricane Irene on August 24, 2011, after some image

Fig 2 (a) EIR Image of Hurricane Irene on Aug.24-2011

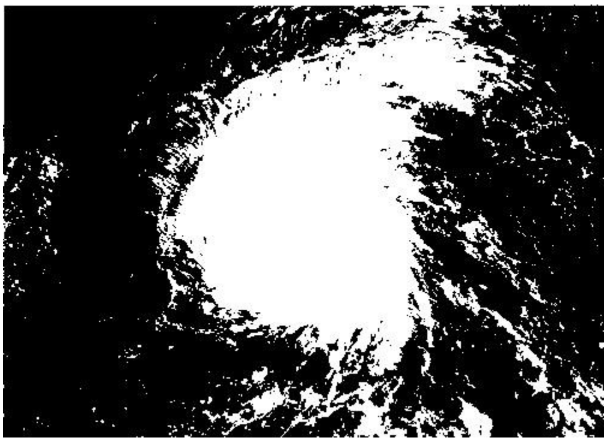

Fig. 2(b) Image of Irene 2(a) after Otsu thresholding

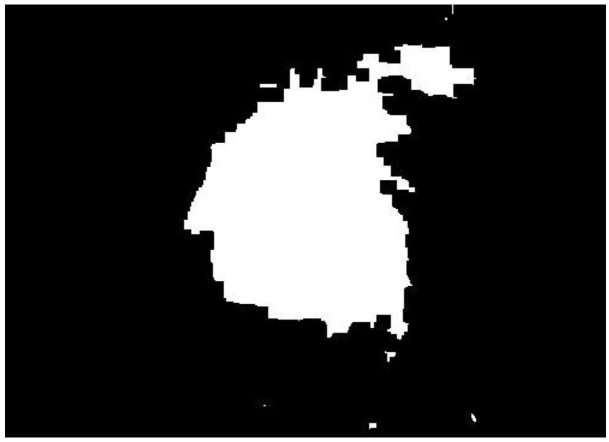

Fig. 2(c) Image of 2(b) after noise removal

pre-processing operations have been carried out.

The pre-processing operations have been applied to all th images. Some examples are shown in Figures 3 and 4. Figure 3 represents original images of hurricanes Elida and Flossie (EIR,courtesy NOAA) and cyclone Ward (VIS, courtesy IMD), while Figure 4 represents images of Elida (row 1), Flossie (row 2) and Ward (row 3) after Otsu thresholding (column 1), Morphological

histogram. The algorithm assumes the image is compressed of two basic classes foreground and background, thus easy to implement. Because Otsu threshold operates on a histogram it is quite fast. Additional noise is then removed using the morphological DILATION/EROSION operation. The sizes of the structuring elements used for opening and erosion are given in Table 1. This operation applies a structuring

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Table 2: ROC Analysis

Sl .no.	Falsely classified T-number	Correctly classified T-number
1	0.56	0.26
2	0.61	0.56
3	0.79	0.82
4	0.88	0.87
5	0.95	0.97
6	1	1

Fig 3: Original Images of (L to R) Elida (EIR, NOAA), Flossie (EIR, NOAA) and Ward (VIS, IMD)

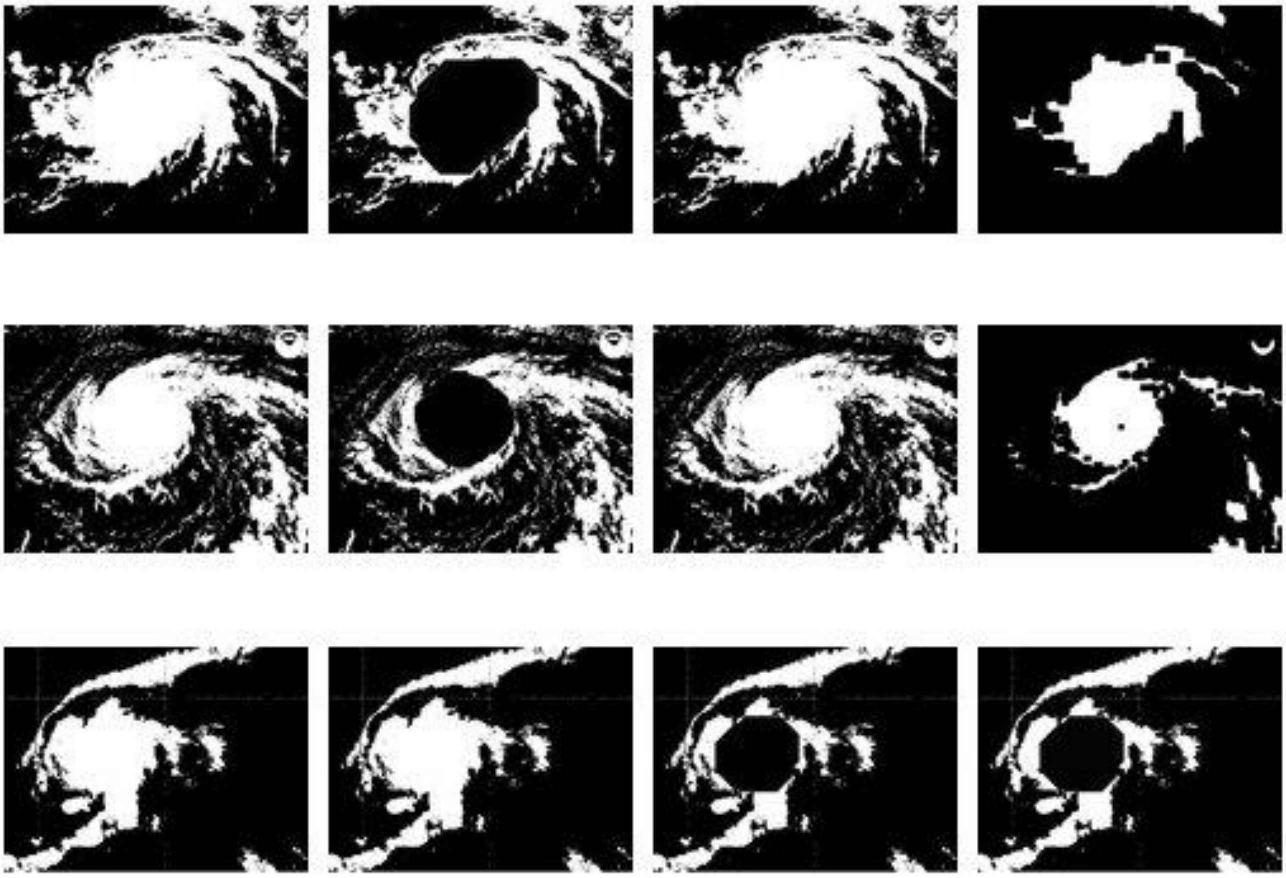
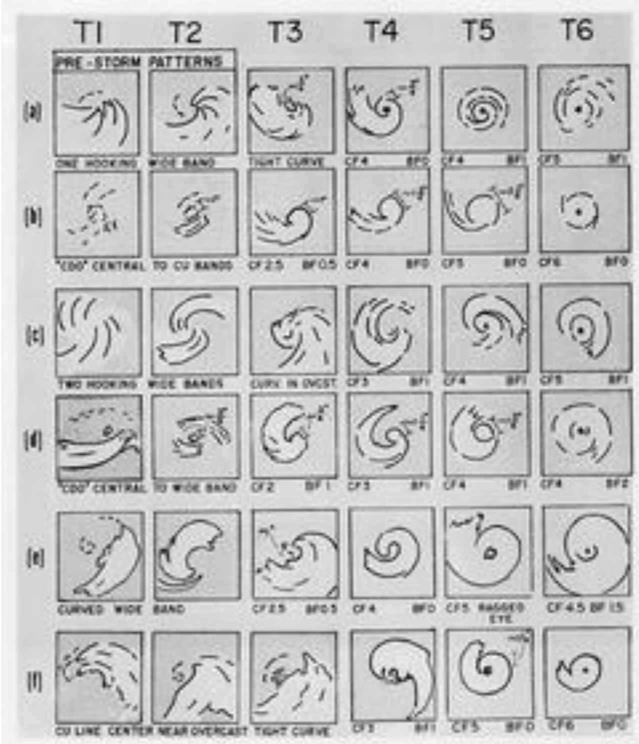


Fig 4: Pre-processing steps of (L to R) Otsu thresholding, morphological opening, flood filling and erosion for (T to B) images of Hurricane Elida, Hurricane Flossie and Cyclone Ward.

Fig. 5: The Dvorak template indicating T numbers of cyclone cloud intensity patterns at



different stages of its evolution

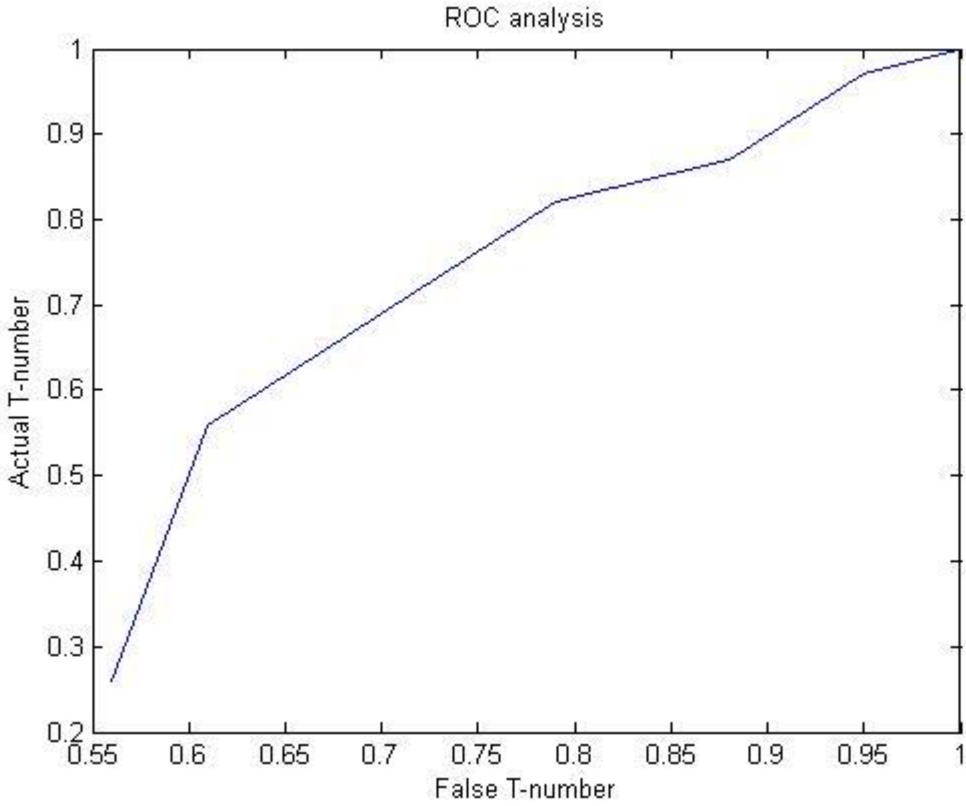


Fig.6 :ROC Analysis

Comparison with other work

Lee and Liu [5] have used the active contour model (ACM) to extract contours and EGDLM for matching to obtain a correct classification rate of 82 %. Lui et.al. [6] have also used ACM along with angle features time warping model for matching to obtain an accuracy varying from 55-83%. Pao [9] using a region growing segmentation technique to obtain an accuracy of 82%. Pineros et. al. [10] used low pass filters coupled with the Sobel operator to obtain a classification rate of 74-80 %. Using skeleton extraction techniques Tsang [11] obtained an accuracy of 75 %. In all these techniques, it was assumed that the cyclone evolution followed a regular evolution pattern of formation, growth intensification and decay.

Our algorithm has an accuracy of 83 %. The method is simple to implement and is robust as it gives good classification for cyclones that have a confusing formation and irregular variations during its evolutionary cycle.

5. CONCLUSIONS

Correct classification of cyclone cloud patterns is important for the prediction of the cyclone evolution and weather prediction. Classification in turn depends on the accuracy of the pre-processing techniques applied to satellite images (both EIR and VIS). The methodology applied above is a simple yet robust approach to preprocessing using Otsu thresholding, morphological opening, flood filling and erosion. These techniques attempt to extract closed contours of the cyclone cloud intensity shapes, which can then be matched [15] with Dvorak templates to make the necessary predictions. This algorithm has been applied successfully to the analysis of hurricane Roxanne, which had a confusing formation and irregular intensification pattern.

The techniques outline above show promise. However, future work will be based on several improvements. Firstly, a more accurate thresholding technique needs to be applied to cater for cloud patterns of varying intensities. Secondly, the technique should be automated. Steps in this direction would include a procedure to extract the dominant cyclone disturbance, threshold and extract unbroken contours.

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