# Wind Field Analysis using Optical Flow and Fuzzy Logic

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## ABSTRACT

Wind field analysis using optical flow is presented. The method is demonstrated for infrared images of clouds over the Indian Ocean region captured by the geostationary meteorological satellite METEOSAT-7 during one year period (2008 August to 2009 July). The optical flow is calculated using Horn-Schunck method for consecutive images taken in every 30 minutes interval. A fuzzy inference system is used to remove false vectors that do not belong to their neighbourhood. The filtered vector field is fed to another fuzzy inference system to identify vector directions and grey levels in the neighbourhood. The resulting image produces regions where the wind direction and cloud height changes rapidly – regions of high atmospheric activity. These regions are labelled and their centroid is calculated for tracking purposes. The calculated wind vectors are compared with the wind diagrams produced by the Indian Meteorological Department.

## 1. INTRODUCTION

Following movements of clouds have long been an important observation in meteorology. The advent of the satellite age brought in remote sensing capabilities that greatly improved the accuracy required in following cloud motion. A global perspective provided from a vantage point beyond the reach of any other equipment makes satellite technology indispensable for the field of meteorology. The flow of clouds is shown on images by the use of cloud motion vectors that give direction and approximate speed. The calculation of these cloud motion vectors allows meteorologists to analyse the wind fields at different levels in the atmosphere [1].

Analysing image sequences is an important area in computer vision, especially for motion approximation. The concept of Optical Flow (now used to describe gradient based methods) was first studied by the American Psychologist James J. Gibson in the 1940s as a part of a theory on affordance. The changes in brightness pattern in an image where the background is considered stationary are assumed to be the result of a translation in the foreground images [2]. Since cloud regions are not seen to make very large displacements during 30 minutes when taken from the height of a geostationary satellite, it makes Optical Flow a good motion estimator for clouds. It is also capable of giving a very dense flow field as motion is calculated for each pixel, thus revealing finer motion in the wind fields. Fuzzy Logic has been used in motion detection in several fields for its ability to produce reliable results from noisy data. The traditional block matching technique is improved upon with the use of fuzzy logic [3, 4].

This paper explores the possibility of using fuzzy logic with optical flow methods to generate cloud motion vectors in satellite images. Using a sequence of infrared satellite images we generate motion vectors for each pixel between two images. Then, the surrounding vectors are compared using fuzzy logic to cluster pixel motion into a general motion in the area. The resulting vectors are calculated for speed and direction, and shown using wind barbs – meteorological signs for wind velocity – on the satellite image.

## 2. DATA SAMPLE

Satellite images are available in many forms; Infrared, Visible, and Water Vapour (see Figure 1). Infrared images of clouds over the Indian Ocean region captured by the geostationary meteorological satellite METEOSAT-7 during the period from 2008 August to 2009 July were used in the present study [5].

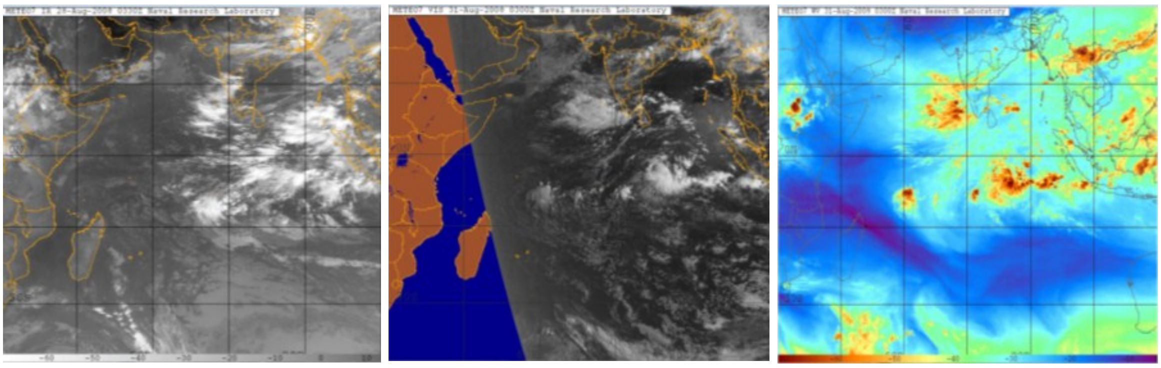

**Figure 1**: Satellite image types. Images from left to right are visible image of clouds, infrared image of clouds, and water vapour image of clouds.

## 3. IMAGE PROCESING

During the calculation of optical flow fields, it was assumed that all points on the image are uniformly illuminated by the Sun. Then, the radiation received at each point is the same and the reflected radiation only depends on the height of the pixel. Imagery such as shadows, variable illuminations and surface transparency will cause this assumption to be violated [6].

### 3.1 Pre processing

The satellite images used are colour images of 700x900 pixels in size. The images first transformed into grey scale for pre processing. As the Meteosat issued images cover a very large area, an area of interest – in this case the region containing Sri Lanka and its surrounding area in the Indian Ocean – are selected for processing. Country borders and grid marked on the images were removed to reduce errors. Gaussian low pass filter with a 3x3 mask, and sigma 0.5 was used to remove some of the Gaussian noise before optical flow is detected.

### 3.2 Cloud Motion Vectors using Optical Flow

The Horn-Schunk method was used to detect optical flow in the cloud regions mentioned above [7, 8]. This method introduces a 'smoothness' or alpha value to solve the aperture problem. Using the image intensity values along the $x$ and $y$ axis, the formulation is considered as an energy field that should be minimized. An alpha value of 4 was used for this work.

### 3.3 Fuzzy Logic Neighbourhood Comparison

The fuzzy system is created to remove the anomalies in the optical flow vectors. Matlab offers 2 types of Fuzzy Inference Systems (FIS) – Mamdani and Sugeno. For this application, the Mamdani FIS was chosen.

The FIS was used to detect if the pixel was a 'cloud' and to detect outliers in the optical flow vectors generated through the Horn-Schunk method. Inputs are greyscale values of the pixels in two consecutive images and the outputs are the average difference in vector direction with respect to the 8 surrounding pixels of a given pixel. Outputs are generated within a range of 0 – 1 depending on how much closer to be a cloud or how similar its direction is to surrounding vectors.

<u>Fuzzy Rule Base:</u>

- If (avg_vector_dif is not is_vec) then (output1 is invalid_vec) (1)
- If (avg_vector_dif is is_vec) and (grey_level1 is not is_cloud) and (grey_level2 is not is_cloud) then (output1 is valid_vec) (1)

Once the fuzzy system gives an output stating the validity of a vector in its neighbourhood, the invalid vectors are discarded. To fill the gaps of these discarded vectors and to give a clearer representation of the whole wind field in the image, an 'average' filter of mask size 10 was used.

Another FIS was used to identify regions of high activity – defined by differences in wind vectors and high spatial gray scale differences – for tracking purposes. Entropy gives a randomness value which gives an impression of the texture of the image. Here, a smooth region has similar gray values, and a rough region has a high gradient in gray levels. Inputs are entropy values of pixel in each input image with respect to greyscale value and the entropy of a pixel with respect to the vectors surrounding it. Output is ranged from 0 – 1 to specify if the region is high in activity for tracking.

<u>Fuzzy Rule Base:</u>

- If (entropy_gray1 is rough) and (entropy_gray2 is rough) and (entropy_dir is rough) then (activity is high) (1)

Chosen pixels were aggregated with the use of Matlab functions into groups. Then the centroids of these systems were calculated to allow tracking of the movement of each system (see Figure 2). The displacement of clouds due to atmospheric winds detected in every half an hour interval was displayed in 3 height categories.

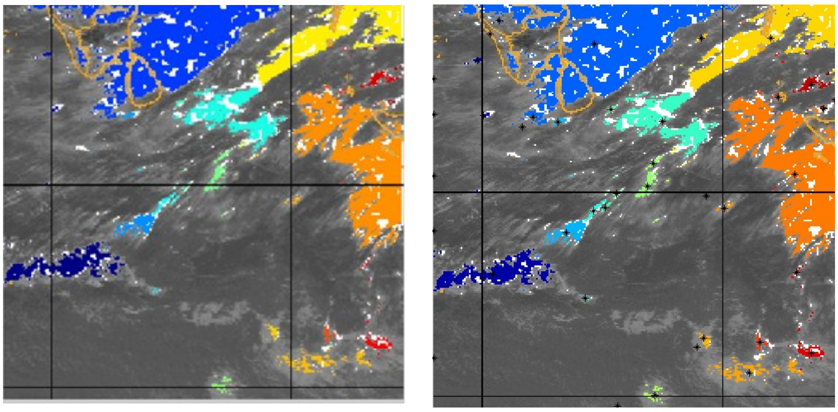

**Figure 2**: (a) Identified regions of interest (b) Same with centroid of regions marked in blue crosses.

## 4. VALIDATION

For initial validation of the optical flow method combined with fuzzy logic, the system was fed with consecutive images of the same system with a 5 pixel translation to the right. The results were as shown in Figure 3.

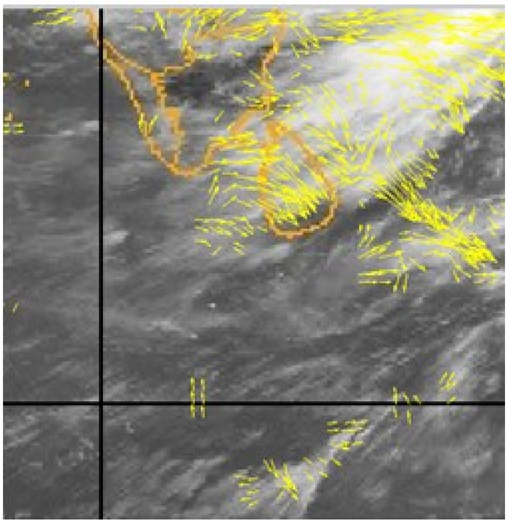

**Figure 3**: Vectors showing translation of 5 pixels to the right

As optical flow follows the gradient of the gray levels of pixels, it is difficult to get exact vectors when dealing with blurred borders of cloud layers.

To validate the wind vectors generated by the system, results can be compared with the wind vector diagrams that are issued by meteorological departments around the world. The Indian Metrological Department issues half hourly wind vector diagrams for the Indian Ocean and greater Indian subcontinent. These vector diagrams show actual wind data taken by radiosonde and other acceptable methods of collecting metrological data. Therefore, their vector diagrams are ideal for validating the wind vectors that are generated through the image processing system discussed in this work.

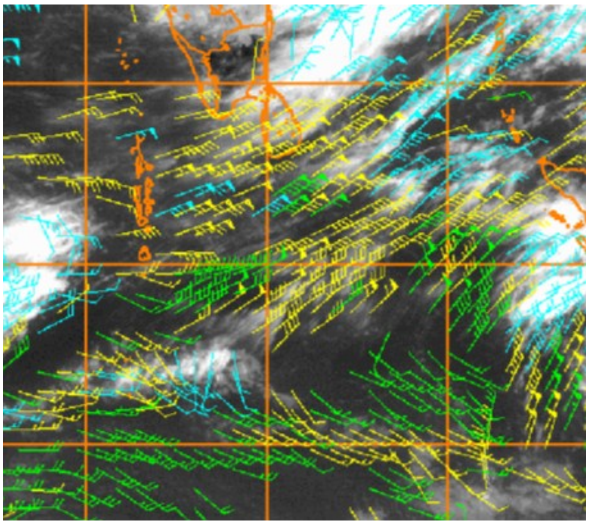

**Figure 4**: IMD issued vectors for 03 Aug 2012 4.30am (green - <300 hPa yellow -300 to 700 hPa blue – above 700 hPa)

## 5. CONCLUSIONS

The optical flow can be used to extract the visible motion of clouds from a sequence of images [9, 10]. Fuzzy logic deals with the calculation and classification in uncertain environments when there are no distinct boundaries between classes. A refined method to improve the accuracy by combining these two methods has been proposed in this work. The optical flow method itself generates wind vectors that have a comparatively low level of accuracy. When the optical flow results are put through a fuzzy inference system which is designed to remove false vectors, a significant improvement was observed. The segmentation of cloud regions based on the entropy values of image greyscale and vector direction was successful in identifying regions of clouds through image processing. The regions of high activity are labelled and their centroids are calculated. The centroids of the labelled regions of high activity can be tracked though time through a sequence of images. The displacements of the centroids can be estimated to obtain the speed of motion of the entire system through the atmosphere.

## ACKNOWLEDGEMENTS:

Financial assistance by the National Research Council of Sri Lanka (NRC grant number 06-18) is gratefully acknowledged.

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