Unsupervised Multi-level Thresholding Method for Weather Satellite Cloud Segmentation

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ABSTRACT

Segmentation is one of the most important tasks in image processing, it seeks to determine whether an intensity value corresponds to a predefined class. Global thresholding is the simplest method for segmentation, it separates the image into two distinct classes corresponding to intensity values located below and above a threshold. However, global thresholding methods have a tendency to over-segment or under-segment areas with relatively inhomogeneous intensity. Multi-level thresholding takes into account spatial variations of intensity in an image, it is obtained by applying to each region of the image a different threshold. In this paper we present an unsupervised multi-level thresholding technique for segmenting cloud areas from weather satellites images. Our approach is to initially generate several binary images from a set of predefined threshold values, then extracting and mapping the contours of the cloudy areas included in the image sequence. The segmented image will comprise all regions whose contour coincides with the outline of a region in the original image.

General Terms:

Image analysis, Weather satellite imagery

Keywords:

Image segmentation, cloud segmentation, multi-level thresholding, contrast enhancement

1. INTRODUCTION

Clouds are highly deformable structures, which appear in different shapes and sizes. They provide important information for atmosphere analysis [1]. With the technological development of meteorological satellites, satellite imagery - with high spectral, spatial and temporal resolution - has become an important source of information for weather forecasting. Hence, the need for efficient and unsupervised methods for the processing and the extraction of useful data. The evolution of image processing techniques - in recent decades - has achieved considerable advances in automatic processing of satellite imagery. Unsupervised segmentation and classification [1] of cloud structures from satellite images is one of the most studied applications in meteorology to improve weather forecasts [2, 3, 4, 5, 6, 7]. The segmentation of cloud areas using simple thresholding techniques (use of a single threshold for the whole image) can not provide all the important structural information of the segmented areas. Indeed, these techniques do not take into account spatial variations of clouds intensity. In this paper we present a multi-level thresholding technique for extracting cloudy areas that correspond to different intensity values.

2. APPROACH

The main idea of our technique is to generate, in a first instance, a sequence of binary images based on threshold values belonging to a predetermined range of values, each threshold value produces a binary image. Then, we extract the contours of cloudy areas from the generated images and we perform a mapping between contours from two successive sequences. The final image will be composed of all regions whose contour coincides with the outline of a cloud region of the original image. To validate our approach, we used a series of real images in the visible spectrum from the geostationary satellite *GOES-15*[2] covering the East Coast of the United States on 26/01/2015[3].

2.1 Preprocessing

Images collected by weather satellites are in raw or unprocessed form, in order to produce good quality images, they must be processed to reduce unwanted distortions or enhance some features required for further processing. *Noise reduction* and *contrast enhancement* are of great interest in image analysis as a preprocessing techniques that improve image quality.

2.1.1 Noise reduction by a Gaussian smoothing. Regularity is a major constraint in the context of digital images, it assumes that luminous properties in a neighborhood of space or a time interval,

[1] A segmentation or classification method is called *unsupervised* when it is not based on initialization parameters or, these parameters are estimated by methods that do not require human intervention.
[2] GOES-15 is part of the Geostationary Operational Environmental Satellite (GOES) system operated by the US National Oceanic and Atmospheric Administration (NOAA)
[3] Satellite images from NOAA-NASA GOES Project `ftp://goes.gsfc.nasa.gov/pub/goeseast/east_coast/vis`

have some consistency and do not change abruptly. However, a raw image often contains noise, it is produced by the physical devices used for image acquisition. In general, the first step in image processing is to reduce the noise and eliminate unwanted details. This is often accomplished by using a *Gaussian blur*.

2.1.2 Contrast enhancement by histogram equalization. The contrast is a quality factor of great importance in satellite imagery. It quantifies the differences between light and dark areas. If the contrast is highly concentrated on a specific intensity range, the information contained in areas with high concentrations may be lost. Satellite images are known for their low contrast, therefor, an enhancement is essential. There are several techniques for optimizing the contrast and better distribute the intensities over all possible values. Techniques based on histogram equalization are the simplest to implement and produce effective results [8, 9, 10, 11]. For example, the *local histogram equalization (LHE)*, the *global histogram equalization (GHE)* or the *adaptive histogram equalization (AHE)*. The later method improves, effectively, the local contact, however, it amplifies noise in homogeneous regions. In our case, we will use the *contrast limited adaptive histogram equalization (CLAHE)* [12] method which is a variant of the adaptive histogram equalization method, it limits the noise amplification. The contrast adjustment is a sub-task of our segmentation approach that will - eventually - be part of a broader process of satellite image processing. (Fig. 1).

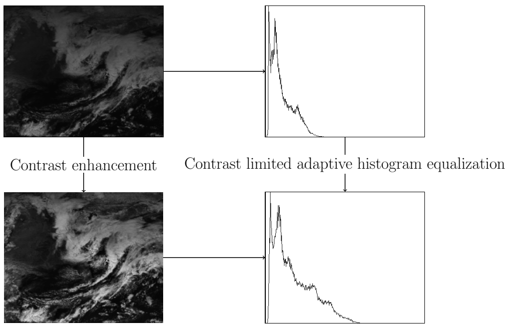


Fig. 1: The contrast enhancement by contrast limited adaptive histogram equalization method

2.2 Multi-level thresholding

2.2.1 Calculating a global threshold. The goal here is to determine a global and coarse threshold that separates the image into two distinct classes, the background and the foreground. The method used should be easy to implement, fast and with no initialization parameters. Sezgin and Sankur [13] presented a classification and evaluation of a number of methods, which they classified into six categories: methods based on the histogram, methods based on the grouping of gray levels into two classes, methods based on the entropy of the image, methods based on the properties and descriptors of the image, spatial methods and finally, local methods. In our approach we have opted for the Otsu's method [14] which is simple, fast and easy to implement, it is based on the image histogram. It minimizes the intra-class variance, defined as a weighted sum of variances of background and foreground classes.

2.2.2 Extraction and identification of contours. The evolution of the contours between two successive thresholding iterations allowed us to distinguish three cases: contours are becoming larger, new contours appear and other contours are merging to create a broader contour. Our goal is to make a mapping between contours from the current iteration and those produced by the previous iteration. Formally, given a set of global threshold values $t_{i=0,\ldots,n}$ such as $t_i \leqslant t_{i-1}$, each value produces a binary image I_t, the set of contours extracted from I_t is denoted C_t. A contour c from actual threshold iteration t_i is mapped to a contour $c^{'}$ of the previous iteration t_{i-1} if c is included in $c^{'}$ such as $c \in C_t$ and $c^{'} \in C_{t-1}$. In addition to the inclusion criterion between the contours, several shape descriptors (as the area of the regions) may be used to effectively identify and map the contours. We build a hierarchical structure reflecting the links between the contours from different thresholding iterations.

2.2.3 Calculating the intensity gradient in the neighborhood of the contours. The matching between the extracted contours during thresholding iterations and those corresponding to the cloudy regions of the original image requires the use of an *edge detection* method on gray-scale images. Two main approaches exist in this context: the search for *local directional maxima* of first order derivative of the image, and the search for *zero crossings* of the second order derivative of the image. A review of the main methods is presented by Ziou and Tabbone in [15]. In our case, we will use the *Sobel* operator [16], which belongs to the first category.

3. ALGORITHM

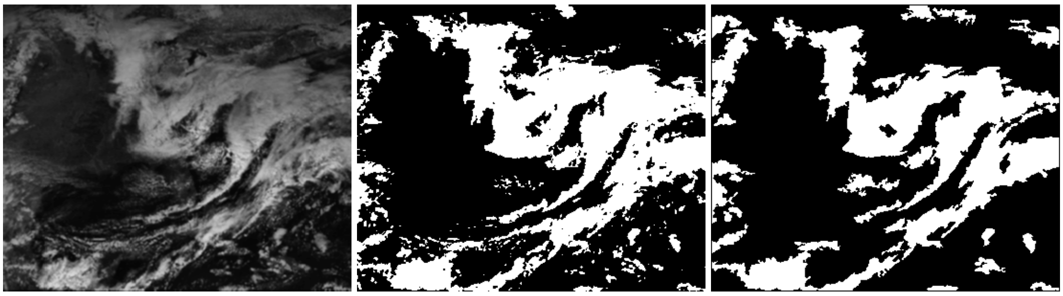
The following steps describe the proposed algorithm for the segmentation of cloud structures from satellite images:

(1) Image preprocessing (noise reduction and contrast enhancement).
(2) Detection of the global threshold T using the Otsu's method.
(3) Determination of the intensity range $[T-d, T+d]\,; T+d \leq 255; 0 \leq T-d$.
(4) Generation of the image sequence $I_{t=T-d,\ldots,T+d}$ and creating a set $C_{t=T-d,\ldots,T+d}$, each containing all contours extracted from image $I_{t=T-d,\ldots,T+d}$.
(5) Constructing a hierarchical structure for mapping between the contours of C_t and those of C_{t-1}.
(6) Computing the average intensity gradient in the neighborhood of each contour in the original image.
(7) Traversal of the hierarchical structure to extract - from every possible path - the contour having the maximum average gradient.

The intensity interval $[T-d, T+d]$ is chosen empirically such that $20 \leqslant d \leqslant 40$. The interval should be large enough to take into account the spatial variations of intensity in the image.

4. RESULTS

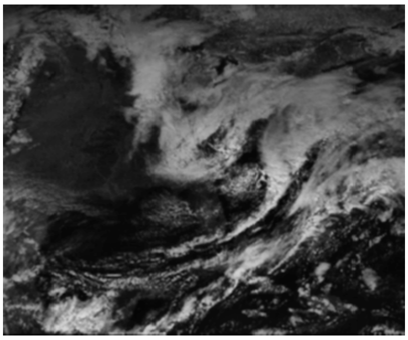
To validate our cloud segmentation approach, we used a series of real images from the geostationary satellite *GOES-15*. We compared the results with those of a global thresholding segmentation using Otsu's method. Figure 3 presents the original image, the image obtained by a global thresholding using the Otsu's method and the image obtained using our multi-level thresholding technique.



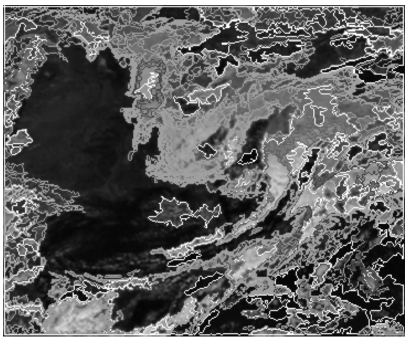
(a) Original image (b) Global thresholding (c) Multi-level thresholding

Fig. 2: Segmentation of cloud structures using: (b) the Otsu's global thresholding method and (c) the multi-level thresholding method presented in this paper.

Using multiple gray level thresholds can extract the most significant cloudy regions of the image while addressing the problems of over-segmentation and under-segmentation (Fig. 4). The final image is the result of multiple thresholding of the original image. The table 1 shows the values of the gray level used to segment the image (Fig. 2a) and the number of regions extracted by each value. For example: the value of 53 will extract 3 correct cloud regions, but, the other regions will be over-segmented (Fig. 4a), while the value of 101 will extract only one correct cloud region, the other regions will be under-segmented (Fig. 4b).



(a) Original image



(b) Contours of cloud areas

Fig. 3: The white contours show the boundaries of the regions of the clouds. The gray contours represent the contours corresponding to thresholding iterations covering the interval $[T-d, T+d]$.

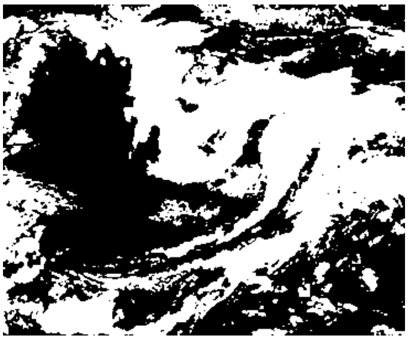
Table 1. : The gray level values used to segment regions of the image (Fig. 2a)

Threshold value	Number of segmented regions
53	3
55	1
57	2
59	1
63	3
65	1
69	2
71	1
73	1
75	2
85	2
87	1
91	2
93	2
97	2
101	1

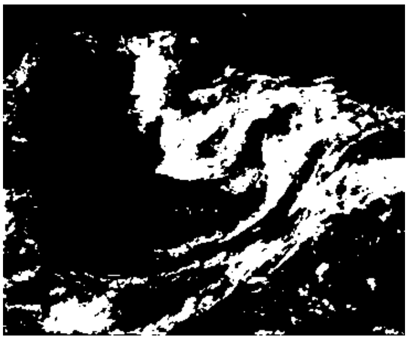
To improve the performance of the algorithm, regions having area smaller than a predetermined value can be ignored. This value will depend on the application field of the algorithm. This will affect the size of the hierarchical data structure constructed in step 5 of the proposed algorithm.

5. RELATED WORK

In recent years, there has been remarkable progress in satellite imagery technologies, particularly those related to meteorological field. In the latter context, several cloud segmentation approaches have been proposed in the literature, they are grouped into two categories : *general purpose* methods and cloud specific methods that exploit the intrinsic properties of clouds (shape, size, temperature . . .) and their interactions with atmospheric elements. The diversity of the frequencies used by image acquisition devices (visible, infrared, water vapor . . .) improves the quality of clouds segmentation by providing prior knowledge about cloud structures



(a) Over-segmentation



(b) Under-segmentation

Fig. 4: Segmentation of (Fig. 2a) using the gray level values 53 and 101: image (a) shows an over-segmentation while image (b) shows an under-segmentation of the original image.

within an image.

In the remainder of this section, we present some research works related to the topic of cloud segmentation from weather satellite images. A contextual statistical labeling method was proposed in [4] to segment low clouds from the uncovered ground surface using infrared METEOSAT images during the nighttime. In [5], authors developed an Adaptive Average-Brightness threshold algorithm: the image is divided into 4 quadrants, then a suitable threshold is determined for each quadrant and applied to each region separately, the algorithm produces fast and accurate segmentation of cloud regions. In [17], authors presented a level-set approach for segmenting cloud structures in satellite image sequences: the level-set procedure is based on implicit functions defined by particle systems, an initial gray scale thresholding is performed to extract the skeleton of the form, then, the particles are initialized using endpoint of the extracted skeleton. In [18], a threshold method is suggested for AVHRR data analysis in the mid-altitudes during the daytime, it enables to detect clouds and precipitation and to determine their parameters. A segmentation approach based on multi-scale convexity analysis in presented in [19], the segmentation is conducted in 2 stages: the generation of cloud regions at coarser resolution and then the construction of the convex hulls of cloud regions using multi-scale morphologic opening and half-plane closings. In [6], a *normalized cuts model* - that was first introduced by Jianbo Shi in [20] - is used to segment satellite cloud images: the image is represented by a weighted graph, where nodes represent pixels and edge weights represent a measure of similarity between pixels. In [21], authors implemented a segmentation method based on *watershed algorithm*: this later is applied to a gradient image obtained using a multi-dimensional morphological gradient, authors used a statistical approach to merge adjacent regions and solve the over-segmentation problem.

6. CONCLUSION

The work we have presented in this paper focuses on a specific cloud segmentation method for images obtained by meteorological satellites. Our approach uses a new multi-level thresholding technique that allowed us, to effectively extract the representative areas of clouds and to solve the problems of over-segmentation and under-segmentation related to global thresholding methods. Depending on the application field, various techniques can be used, either, to select the initial global threshold or to determine a similarity measure for the mapping of contours between different thresholding iterations of the algorithm.

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