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REVIEW: SEGMENTATION ALGORITHMS FOR CLOUD DETECTION

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ABSTRACT
Weather Prediction such as flood detection, storm detection, rainfall prediction and variety of other remote sensing applications depend upon the analysis of weather images. But they consist large data set which is difficult to process as a whole. So, Image Segmentation is often preprocessing step for such applications. Segmentation is done in order to simplify the demonstration of image into something that is significant and easier to examine and observe. Cloud is the major obstacle to analyze data in the weather images as clouds do not possess any exact structure or shape. Also it is broadly recognized that cloud determination is the precondition for deriving information for climate models and climate prediction. That is why it is important and challenging issue to distinguish cloud and sky. In this paper, various existing image Segmentation algorithms for Sky/Cloud detection are reviewed.

KEYWORDS: Thresholding, Minimum Cross Entropy, K-means and Fuzzy Clustering, Neural Network Based Segmentation, Superpixel Segmentation

INTRODUCTION
The division of an image into meaningful structures, image segmentation, is often an essential step in image analysis, object representation, visualization, and many other image processing tasks. Image Segmentation refers to the partition of an image into set of regions. It is the process of observing the image and dividing the contents inside the image into various segments having common characteristics such as color, semantics meaning etc. Segmentation algorithms are based on the basic properties of intensity values i.e.discontinuity and similarity. In discontinuity based algorithm assumption is that boundaries of region are sufficiently different from each other and detection is based on local discontinuities in intensity. There will be abrupt change in intensity at the boundaries of region. Edge based segmentation algorithm belongs to this category. While, Similarity based category partitions the image into regions that are similar according to a set of predefined criteria. Thresholding, Region growing, region splitting are the examples of methods in this category [1]. Most of the cloud detection methods are based on Thresholding. Thus these methods belong to second category. Focus of segmentation is on methods that find the particular pixels that make up an object. The Goal is to represent the meaningful area of the image which is required such as crops, urban areas, forests, clouds from satellite images.

Sky/Cloud detection plays a vital role in solar irradiation; eliminate modeling, weather prediction and analysis of signal attenuation in satellite and other space to ground communications [2]. Thus, accurate segmentation which detect the cloud and sky is of immense importance.Cloud’s characteristics such as height, location, appearance greatly influence the Earth’s energy balance, climate, and weather. Even small changes in location of clouds could change the climatic conditions [3]. Moreover, cloud cover evaluation also plays a guiding role in flight planning and aviation. Clouds consists certain characteristics such as location, intensity, color , thickness, texture, shape or size which varies from one cloud to another. Therefore, It is difficult to distinguish sky and clouds manually.

Sky/Cloud cover detection is the preliminary step. Cloud detection is the basic source of information to determine cloud brokenness, fractional sky cover and cloud distribution. However, this issue is particularly challenging due to the severe illumination changes and vague boundaries between cloud and sky regions. Various Segmentation algorithms are applied in literature on weather images to detect Sky/Cloud cover. They are reviewed in the next section.

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VARIOUS IMAGE SEGMENTATION TECHNIQUES

The traditional methods of performing cloud analysis through satellite images do not provide sufficient resolution for some applications and may contain errors. For example small clouds are often overlooked. Because of similar brightness and temperature of Low clouds and surface, are frequently confused. The resolution problem can be overcome by using sky-image devices such as Whole Sky Imagers (WSI) , Total Sky Imager (TSI) etc. WSI can be used to examine fractional sky cover. Unfortunately, Due to high-quality components and sophisticated engineering involved, these imagers are often too expensive which puts the WSI beyond the means of many individual researchers and research groups [4].

A. Fixed Thresholding

When the entire image is segmented with the same fixed threshold value that is known as Fixed thresholding. Single value of threshold can simply be used to differentiate both foreground and background. Long et al. presented the pixel classification based on RGB color channel. In scattering characteristics of atmosphere more blue light is scattered than red, that's why the clear sky (no aerosols) appears blue to our eyes. Red/Blue ratio is small, for clear sky ,that is, dark in the image, but increasing near the sun and near the horizon. Clear sky scatters more blue light unlike clouds which scatter red and blue visible light equally. So the relative ratio will be more for clouds than clear sky. The lower limit is set to 0.6. Pixels with red to blue ratio greater than this value will considered as cloud otherwise cloudless. This means lower limit 0.6 behaves as a threshold value.

With R/B ratio discussed above, there is a problem in detecting thick clouds. Therefore, criterion to detecting clouds is modified and use the difference R-B rather than ratio R/B. Threshold value is set to R-B=30. Pixels R-B>30 are considered as cloud otherwise cloud free [5]. Finally, Euclidean geometric distance (EGD) was recently put forward for the classification of sky and cloud patterns observed that sky and cloud patterns occupied separated loci on the RGB color space; hence, they made use of the EGD and Bayesian methods to distinguish cloud from sky pattern. All of these methods detect clouds using fixed thresholds, they are categorized as fixed thresholding algorithms [6].

B. Segmentation under Low Visibility Conditions

Fixed Thresholding algorithms do not considers the Aerosol optical Depth factor to set the threshold value. But it is realised that in relation to scattering of blue light, AOD also impacts the sky color which will appear whiter when more aerosol particles present in the atmosphere. Avoiding aerosol pixels for threshold setting will wrongly determines the cloud. Also, Aerosols such as dust, smoke, droplets of water occurring as snow, fog also effects the visibility. Visibilty is inversely related to the presence of aerosol particles.

Correctness probability (A_c) is measured in order to evaluate the results of fixed thresholding under low visibilty conditions. When AOD is greater than 0.86, it has been noticed that correctness probability decreases which shows that aerosol particles influence the accuracy under low visibilty conditions.

Integrated method for cloud determination under such conditions is given by Huo and Lu. First, Fast Fourier Transform (FFT) is applied to sky images. It will help to analyze whether the image is homogeneous or not which will lead to detect the existence of cloud in an image because cloudless image is more homogeneous. B/R ratio difference for the symmetrical pixel is calculated. Difference should not exceeds the limit which is predefined, then both pixels are set to cloudy (or cloudless) by comparing their ratio with the threshold value. But if it exceeds the limit, pixels can be cloudy or cloudless depending upon ratio. Histogram of the B/R ratio is used to set the threshold value.The threshold is selected from the intervals which consists two greatest numbers. Then, Edge searching method is performed to determine clouds. For the whole image, standard deviation and B/R ratio is calculated. Pixels with highest 20 standard deviations are further analysed. B/R ratios of such pixels are then averaged to determine new threshold value. The final threshold is obtained by averaging the values determined by the histogram and edge searching methods .

However more future work is required for thin cloud determination under low visibility conditions which is not correctly determined by this integrated method [7].

C. Cloud Detection Algorithm Based on Mean and Hybrid Methods

Existing methods such as Mean, Second Highest Methods individually are more suitable for static images, small size images and less cloud cover regions. Another Cloud detection method which combines Mean and Hybrid method is needed. The resultant of proposed method is capable to detect the clouds of both high as well as of low brightness with preserving the quality of image. Proposed method is based on averaging the pixel values.The steps for cloud detection are as follows:

a. Read an input image
b. Convert the RGB color image to gray scale image
c. Find column wise and row wise mean for input image

Consider the input image A_{ij} where 'i' and 'j' are row and column of matrix. Column wise mean is computed as follows:

$$A_{j}=\frac{\Sigma j}{N} \quad (1)$$

where 'j' represents the column values and 'N' is the total number of columns in an image.Row wise mean is computed as follows:

$$A_{i}=\frac{\Sigma i}{M} \quad (2)$$

Where i represents the row values and 'M' is the total number of rows in an image in equation (2).

d. Cloud detection based on computed column wise and row wise mean

Each pixel in image is compared with the column wise mean value. If mean value is greater than that pixel value it is considered as cloud and remaining values are compared with row wise mean values. If the pixel value is lesser than the mean value then that values are considered as sky.

Though this method preserves quality of image but it is not able to detect some type of clouds such as thin clouds. Development of better algorithm which is applicable to all types of clouds, is still a challenging task for the researchers [8].

D. Hybrid Thresholding Agorithm (HYTA)

Fixed thresholding algorithms are not able to determine the thin clouds correctly whereas adaptive thresholding algoritms does not work well on other types of clouds like stratiform and clear sky images. So HYTA was developed which integrates the fixed and adaptive thresholding algorithms.Sky images can be either unimodal or bimodal. Unimodal images consist of only one element either sky or cloud. But Bimodal images made up of both sky and cloud elements. After transforming the image into feature image (say B/R ratio) evaluate the histograms of unimodal and bimodal images. The histogram of unimodal images has generally single peak. But histogram of bimodal images has two or more peak and large variance. Also, there is significant differences in their physical and statistical characteristics. That's why it is reasonable to treat them with different algorithms for more accuracy. All these factors are considered by HYTA results in more accuracy.

First step in HYTA is to normalization of B/R ratio. It is necessary step in order to improve the visual contrast and robustness to noise. Even a single noisy pixel in image can cause difficulty in cloud detection. Normalized B/R ratio is given as follows:

$$\lambda_N = \frac{b-r}{b+r}, \quad (3)$$

Second step in HYTA is to determine whether the image is unimodal or bimodal. For this purpose, compute standard deviation and if it is greater than T_s=0.03 then image is considered as bimodal otherwise unimodal. Unimodal images will be treated with fixed thresholding algorithms. But Bimodal images will use MCE thresholding method to detect cloud as shown in Figure 1.

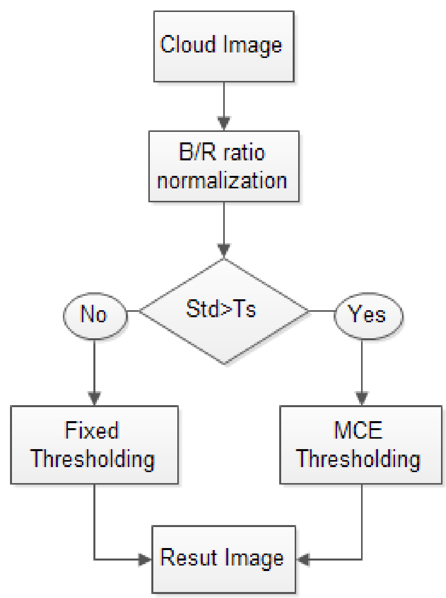

***Fig. 1** Block Diagram of HYTA Algorithm*

Minimum Cross Entropy Thresholding

The MCE thresholding algorithm selects a threshold by minimizing the cross entropy between the original image and its segmented image. Let In be the normalized B/R ratio image and h(i) be the corresponding histogram. Segmented image B_t with t as the threshold value, is computed in equation (4) as follows:

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$$B_t(x,y) = \begin{cases} \mu(1,t) & ln(x,y) < t \\ \mu(t+1,L), & ln(x,y) \geq t \end{cases}, \quad (4)$$

where x and y are the pixel coordinates and μ(a, b) is given as:

$$\mu(a,b) = \sum_{i=a}^{b} ih(i) \Big/ \sum_{i=a}^{b} h(i) \quad (5)$$

Then cross entropy between In and B_t is calculated, denoted by D(t). The MCE determines the optimal threshold t* by minimizing the cross entropy D(t) as in equation (6),

$$t^* = arg\ min[D(t)] \quad (6)$$

This t^* is used to detect clouds. Pixels whose normalized ratio values are less than t* are considered as clouds; otherwise sky. Thus proposed method combines the fixed and adaptive thresholding algorithms. However, this method was not well suited for real world applications [9].

E. Fusion Segmentation Algorithm

Another method for sky/cloud detection is presented by fusing K means Clustering with Neural Networks. First, detect the clouds using the NN classifier. Then the results are post-processed and fused with the results obtained by K-means Clustering Algorithm.

Neural Network Based Segmentation

In this algorithm, an image is firstly mapped into a neural network where every neuron represents a pixel. The neural network is trained with gradient descent method in order to determine the connection and weights between nodes. Then the images are segmented with trained neural network. Neural network segmentation includes two important steps:
(i) Feature extraction- This step determines the input data of neural network. Some important features from images are extracted that will help in image segmentation. Here 15 input features, 20 nodes in the hidden layer and an output node.
(ii) Image segmentation- In this step the image is segmented based on the features extracted from the images. Output node indicates "1" for the sky and "0" for non-sky regions.

Fusion Algorithm

At the fusion step, intersection is taken between each region determined using K-means and the corresponding region computed as sky in NN classifier [10]. Fig. 2 shows the block diagram of the proposed sky segmentation algorithm.

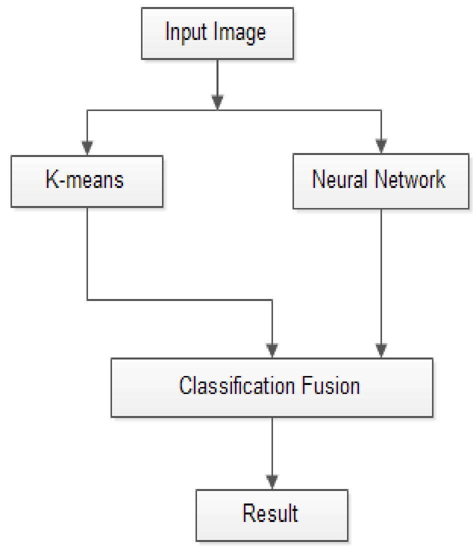

Fig. 2 Block Diagram of Fusion Algorithm

F. Fuzzy Clustering Algorithm

Fuzzy clustering can be used in situations when there is no defined boundaries between different objects in an image.Fuzzy Clustering (Soft Clustering) assigns the degree of membership ranging from 0 to1 of an object to a given cluster.It allow an object to belong to more than one cluster.
Steps to perform Fuzzy clustering:

Step1: Randomly selects the 'c'cluster centers.
Step2: Calculate the fuzzy membership using 'uij' using

$$uij = 1 \Big/ \sum_{k=1}^{c} (dij|dix)^{\frac{z}{m-1}} \quad (7)$$

Where 'uij' represents the membership of ith data yo jth cluster center
dij =Euclidean distance between ith data and jth cluster center
m=fuzziness index
Step3: Compute the fuzzy centers
Step 4: Repeat 2 and 3 untill minimum objective function is not achieved

$$\sum_{i=1}^{n} \sum_{j=1}^{k} uij.d(xi,cj) \quad (8)$$

In recent years, color has been used as the predominant feature for sky/cloud segmentation. However, the selection of color models and channels in the existing algorithms seem ad-hoc in manner, without systematic analysis or comparison. This issue is addressed by providing a structured review and evaluation of color models for the segmentation of sky/cloud images. For this purpose, make use of

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color distribution characteristics, principal component analysis (PCA), and Fuzzy clustering methods [2].

G. Combination of Watershed and Region of Interest Segmentation Algorithm

Both visible and infrared satellites are used to capture the sky images. The clouds that are not very white are called Thin Clouds and the identification of a thin cloud is difficult to find out. Some algorithms for spotting thin clouds are proposed. HSL (Hue Saturation Light) is used for finding the color ratio in the sky image, ROI (Region of Interest) is used for removing the cloud and the sky elements of the cloud image in order to determine the region of interest, Watershed algorithm is used to segment the Thin Clouds [11].

H. Two Step Segmentation

Combination of fixed and adaptive thresholding algorithms was well suited for thick clouds. But it is comparatively difficult to detect thin clouds due to the similar pixel intensities. The enhanced two step segmentation was developed. In the proposed method there are two staegs for cloud detection. At the first stage optimal global threshold is applied to detect the existence of thick clouds in image. By averaging the pixel intensities of whole image, T is computed. Then each pixel is compared with this computed T. If the pixel intensity is greater than T, then it is spotted as cloud otherwise cloudless. Update the threshold value T' by calculating th mean values of the cloud μ_c and ground μ_g.

$$T' = \frac{\mu_c + \mu_g}{2}, \qquad (9)$$

This process continues iteratively untill the mean values get stable point.

$$\begin{cases} T > 500, & cloud \\ otherwise, & cloudfree \end{cases}, \qquad (10)$$

At the second stage thin clouds are determined. Local threshold value is to be calculated for thin clouds. Local threshold is given as follows:

Step1: Local contrast C_{local} for the P_{center} is equal to the difference between maximum intensity value and minimum intensity value within the local window U(x,y)

$$C_{local} = (U_{max} - U_{min}) \qquad (11)$$

Step2: This local contrast is then compared with the user provided threshold value T''

If $C_{local} \geq T''$ then
$T_{local} = (U_{max} + U_{min})/2$
else
$T_{local} = T'$

If local contrast is above or euals to user given threshold value then T_{local} is determined by obtaining mean of the U_{max}, U_{min}; otherwise it is set to global threshold value obtained in stage 1.

Step3: T_{local} acts as a local threshold value for pixel P_{center}.

If $P_{center} \geq T_{local}$ then
$P_{center} \leftarrow 1$
else
$P_{center} \leftarrow 0$

Above procedure shows that if T_{local} is less than or equals to pixel value then P_{center} is considered to be cloud otherwise cloudless [12]. Experimentally this method shows 93.29% accuracy.

I. Superpixel Segmentation Algorithm

Superpixel Segmentation (SPS) Algorithm divides an image into series of irregular image blocks, each block is known as superpixel. This division is based on texture similarity, brightness similarity and contour continuity. Then local threshold value is determined for each superpixel. This results in threshold matrix obtained by interpolating the all local threshold values of superpixels. Finally, Cloud is determined by comparing the featured image with threshold matrix pixel by pixel.

Algorithm:

Step1: Transfer RGB image into R-B feature image, which is basically the difference of R-channel and B-channel. This featured image is used for comparison.

Step2: Normalize the R-B featured image elements to the range of 0 ~ 255

Step3: Compute local threshold for each superpixel on the R-B featured image as follows:

(i) Determine the global threshold value T_g
(ii) Compute maximum value W_{max} and W_{min} minimum value for the R-B featured image.
(iii) Also, Compute maximum value L_{max} and L_{min} minimum value for each superpixel.
(iv) Compute local threshold for each superpixel as follows:

$T_l = L_{max}$, if $L_{max} < T_g$
$T_l = L_{min}$, if $L_{min} < T_g$
$T_l = \frac{1}{2} S_l + \frac{1}{2} T_g$, otherwise

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where S_l is the threshold of each superpixel, which is determined by Otsu algorithm.

Step4: Calculate the threshold matrix after obtaining the threshold value for each superpixel by bilinear interpolation.

Step5: This threshold matrix is used to detect the clouds. Calculate difference between the R-B featured image and threshold matrix. If the resultant value is greater than 0, then that pixel will set to cloud otherwise cloudless.

This method is best suitable for the situation when cloud and sky pixel exists in same superpixel [13].

J. Ground Based Graph Cut Algorithm

Though continuous research in this field provides certain level of accuracy, but results was still unsatisfactory for real world applications. In order to provide more accurate results ground based graph cut algorithm was developed. There are two stages in the proposed method.

At the first stage, automatically label the pixels as 'cloud' and sky by setting the threshold value according to the characterstics of clouds such as color. At the second stage these cloud pixels acts as hard constarints to graph cut algorithm for further detection.

Automatically Acquiring Hard Constraints

Step 1: Convert the RGB image into R/B featured image to get the better contrast and gives more clarity about cloud and sky pixels

Step 2: Determine the threshold value T using otsu algorithm

Step 3: To avoid the misclassification of cloudy pixels refine the threshold value with high confidence. Use θT instead of T to find the hard constarint pixel values. Pixel values less than $(1/\theta)T$ are considered as clear-sky elements. It can be written as:

$$\begin{cases} i \in cloud & l > \theta T \\ i \in clear\ sky, & l < (1/\theta)T \end{cases} \quad (12)$$

Where i is cloudy pixels of image and θ is a parameter controlling the confidence of hard constraint seeds whose value is greater than 1.

Graph Cut Algorithm

Obtained hard constraints are the inputs to the graph model. Let $G = \{V,E\}$ be a weighted undirected graph, where V is a the pixels of the cloud in image and E is a set of weighted edges connecting two pixels. The cost of cut is the total sum of costs of all edges.

$$C = \sum_{e \epsilon C} W_e \quad (13)$$

The cost function acts as the soft constraints for cloud and sky segmentation . This proposed method shows maximum accuracy of 94.7% than above all methods [14].

PERFORMANCE EVALUATION

The major metrics to evaluate performance of cloud detection algorithm are derived from confusion matrix. It consists of four possible outcomes. These are true positive (TP), false positive (FP), true negative (TN), false negative (FN). Confusion matrix is formulated as follows:

Table 1. Confusion matrix for Cloud Detection

	Cloud	Sky
Cloud	TP	FP
Sky	FN	TN

Here, 3 metrics are adopted on the basis of confusion matrix which are precision, recall, accuracy. Accuracy can also be defined in terms of F-measure. Inverse relationship exists between precision and recall. Accuracy is the probability of detecting cloud and sky correctly [8].

Objective Analysis

Objective analysis is done by calculating above mentioned three metrics as follows:

$$Pr = \frac{TP}{TP+FP}, \quad (14)$$

$$Rc = \frac{TP}{TP+FN}, \quad (15)$$

$$Ac = \frac{(TP+TN)}{(TP+FN+FP+TN)}, \quad (16)$$

The above equations (14), (15), (16) are referred from [8]. These are used to evaluate performance of various methods such as Fixed Thresholding, Eulidean Distance (EGD), Hybrid Thresholding Algorithm (HYTA), Selection of color spaces (here for R/B) and Superpixel Segmentation Algorithm. The below table values are in [2],[8],[13].

Higher value shows more accuracy. It can be easily seen from the above table that Superpixel Segmentation Algorithm (SPS) has higher values for all three metrics which makes it more efficient and accurate algorithm.

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Table 2. Comparison Of Various Methods

Research Year	Method	Precision (Pr)	Recall (Rc)	Accuracy (Ac)
2006	Fixed (T=0.575)	0.7200	0.7919	0.7992
2009	EGD	0.6607	0.7224	0.8853
2011	HYTA	0.8425	0.7224	0.8853
2014	Color Spaces	0.84	0.92	0.85
2015	SPS	0.94	0.92	0.93

Subjective Analysis

Fixed thresholding methods are not suitable where AOD is low (less than 0.48). To remove this limitation Algorithm was developed for low visibilty conditions. However, this method was not able to detect thin clouds (e.g. cirrus).Thin cloud detection where AOD is relatively large, was still a challenging task. Combination of watershed and region of interest segmentation algorithm put forwards for thin cloud detection, but this method does not give satisfactory accuracy. Various methods come into existence to improve the accuracy such as Ground based graph cut Algorithm, Superpixel Segmentation (SPS) and Two Step Segmentation, But Graph cut Algorithm is most accurate method with 94.7% accuracy for cloud detection. The below table is formulated from [4],[7],[11], [12],[13], [14].

Table 3. Subjective Comparison Of Methods

Method	AOD	Thin Clouds	Accuracy
Fixed	Applicable for AOD<0.48	Not Applicable	Less Accurate
Under Low Visibility	For AOD>0.48	Not Applicable	Less Accurate
Watershed	Not Applicable	Applicable	Less Acc.
SPS	Not Applicable	Applicable	93.29% Accurate
Two- Step Segmentation	Not Applicable	Applicable	93% Accurate
Graph Cut Algoritm	Not Applicable	Applicable	94.7% Accurate

CONCLUSION

In this paper, existing cloud/sky segmentation algorithms are presented. Traditional methods of cloud cover detection through satellite images do not provide sufficient resolution. Whole Sky imager and Total Sky imager provide resolution but at very high cost.

In recent years cloud color (RGB color model) and brightness are used as predominant feature to distinguish cloud and sky. Fixed Thresholding based on RGB model was not suitable for various clouds such as Thin clouds. So Hybrid algorithms like superpixel segmentation, HYTA and two step segmentation method were developed. None of these algorithms was able to segment cloud and sky under low visibility conditions. An algorithm was developed which considers the aerosol factor for low visibility conditions. Development of single segmentation algorithm applicable to all types of clouds is still a challenging area for the researchers.

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