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Otsu Image Segmentation Algorithm: A Review

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ABSTRACT- Cleaving of an image into meaningful structures, Image Segmentation, is habitually a pre-eminent step in Image processing tasks. Image Segmentation is an approach of partitioning a digital image into diverse set of segments. There exist assorted image segmentation techniques, among all, Otsu method is one of the most successful methods for image thresholding because of its elementary calculation. Otsu is an automatic threshold selection region based segmentation method. In this paper, Otsu method, along with its drawbacks and improvements is reviewed, discussed and finally a brief discussion of various proposed Otsu algorithms is accomplished.

KEYWORDS: Thresholding; Image processing; Otsu's algorithm; Image segmentation**.**

I. INTRODUCTION

Image Segmentation is an approach of partitioning a digital image into diverse set of segments. The premier intention of Segmentation is to simplify representation of an image into something easier to analyze [2]. There exist assorted image segmentation techniques, which segregate image into several parts based on certain image traits like pixel intensity, color, texture, etc. These techniques are sorted on the basis of segmentation method used [1]. The cardinal applications of Image segmentation are Recognition tasks, Content based image retrieval, Medical imaging, Object Detection, Traffic control systems, Video Surveillance, etc. The Image segmentation approaches can be categorized into two types based on properties of image.

A. *Discontinuity detection based approach*

In this approach an image is segregated into sections hinged on discontinuity. The edge based detection is one of the segmentation methods in which edges derived from intensity discontinuity, are detected and associated resulting in boundaries of sections [4].

B. *Similarity detection based approach*

In this approach an image is partitioned into sections rooted on similarity, i.e. regions utilizing similar set of pixels. Thresholding techniques, Clustering Techniques, Region growing techniques and Region splitting and merging are categorized under this approach [4].

Thresholding is the most elementary technique that permutes a grayscale image to binary image, and is employed in majority of image segmentation applications [2]. Through the entire thresholding process, each discrete pixel within the bounds of an image is indicated as object pixel if it's value is more than the sum threshold value and as background pixel if it's value is less than the threshold value. This principle is known as the threshold above and vice versa is true for threshold below [7].

Typically, an object pixel is assigned a value '1'while the background pixel is assigned a value '0' [4].Eventually, a binary image is engendered by coloring each and every pixel white or black, depending upon the pixel's labels [2] .

If $q(x,y)$ is a threshold version of $p(x,y)$ at some global threshold T, it can be defined as:

$$q(x,y) = \begin{cases} 1 \; if \; p(x,y) \geq T \\ 0 \; if \; p(x,y) < T \end{cases} \qquad \text{eq. (1)}$$

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Thresholding operation is defined as:

$$T = M\,[x, y, f(x, y), p(x, y)]\ [14] \qquad \text{eq. (2)}$$

In this equation, T indicates the threshold value, $p(x, y)$ is the gray value of point $(x, y)$and $f(x, y)$denotes some local property such as the average gray value of the neighborhood centered on point (x, y) [14].

II. OTSU'S THRESHOLDING

A Class Variance method known as Otsu's method was presented by Nobuyuki Otsu in the year 1979, for the ease of calculations, consistency and effectiveness. Otsu's method is one of the effective processes employed for the selection of threshold and is well known for its rare time consumption [6]. Otsu's thresholding method involves iteration along the entire probable threshold values and evaluation of standard layout for the entire pixel levels that occupy each side of the threshold [14]. The predominant objective is to compute the threshold value at positions where the addition of foreground & background spreads is minimally possible. Initially, a gray level histogram is a key requirement in the Otsu's thresholding However; it does not give satisfactory segmentation results when it comes to one dimensional plane [9]. Hence, two dimensional Otsu algorithms were proposed to overcome the weakness of one dimensional Otsu algorithm [13]. Two Dimensional Otsu algorithms work on gray-level threshold of each pixel and its spatial correlation information as well. As a result, Otsu algorithm attains satisfactory segmentation results when practiced under noisy constraints [8]. Consequently, copious techniques were proposed to reduce time spent on complex calculations and maintain acceptable thresholding results. Moreover, a fast recursive technique was presented in order to reduce computational time [9]. Otsu's method is one of the better threshold selection methods for real time images with respect to uniformity and shape measures [11]. However, Otsu's method employs a profound search to evaluate the criteria for expanding the within-class variance. As the number of classes in an image increases, the time constraint for multilevel threshold selection also increases.

III. OTSU'S METHOD

Otsu's method is deployed by several image processing applications to execute histogram based image thresholding or to transform a gray level image to a binary image [11]. The algorithm presumes that the image embraces bi-modal histogram (for instance, foreground and background pixels) and further evaluates the optimum threshold, partitioning aforementioned two classes so that their joint spread (intra-class variance) is negligible. The extension of the basic method to multi-level thresholding is named as Multi Otsu method [15].

In Otsu's method we minutely explore the threshold that minimizes the intra-class variance (the variance within the class), defined as a weighted sum of variances of the two classes:

$$\sigma^2_\omega(t) = \omega_0(t)\,\sigma^2_0(t) + \omega_1(t)\,\sigma^2_1(t)\ [19] \qquad \text{eq. (3)}$$

Aforementioned weights $\omega_0$and $\omega_1$are the probabilities of the two classes separated by a threshold ***t*** and σ^2_0 and σ^2_1 are variances of these two classes.

Otsu formulates that minimization of the intra-class variances is correlative to maximization the inter-class variance as:

$$\sigma^2_b\,(t) = \sigma^2 - \sigma^2_\omega(t) = \omega_1(t)\,\omega_2(t)\,[\mu_1(t) - \mu_2(t)], \qquad \text{eq. (4)}$$

That is expressed in the terms of class probabilities ω_i,and class means μ_i. [18]

The class probability $\omega_1(t)$ will then be calculated from the histogram ***t*** as:

$$\omega_1(t) = \sum_0^t P(i)\ [19] \qquad \text{eq. (5)}$$

Whereas, the class mean $\mu_1(t)$ is given as:

$$\mu_1(t) = \sum_0^t P(i)x(i)\ [19] \qquad \text{eq. (6)}$$

Where $x(i)$is the value at the centre of the histogram bin.

The class probabilities and the class means are computed iteratively which yeilds an efficient algorithm [19].

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Algorithm:

1. Figure out histogram and probabilities of each intensity level
2. Set up initial $\omega_i(0)$ and $\mu_i(0)$
3. Rank through entire possible thresholds ranging from t=1 to maximum intensity
   i. Update ω_i and μ_i
   ii. Compute $\sigma_b^2(t)$
4. Desired threshold corresponds to the maximum $\sigma_b^2(t)$ [19]

IV. LIMITATIONS

Otsu's method exhibits relatively good performance if the histogram retains bimodal distribution and is inferred to utilize a deep and sharp valley linking two peaks except the fact that the object area is small as compared to the background area, the histogram no longer exhibits bimodality [6]. Furthermore if the variance of the object and the background intensity is large compared to the mean difference or the image is corrupted due to noise constraints, the sharp valley of the gray level histogram is perverted and the incorrect threshold influenced by Otsu's method terminates in the segmentation error[7].

V. IMPROVED OTSU ALGORITHM

Frequent enhancements have been proposed for various limitations of Otsu's method. Among them a well known enhancement is referred as Two-dimensional Otsu's method. In this approach, the gray-level value of each pixel as well as the average value of its immediate neighborhood is studied so as to improve the binarization results of the images distorted by noise [11].The average gray-level value of the neighborhood is computed for each pixel. Assume that the gray level of any image is partitioned into L values and the average gray level is also segregated into same L values. Furthermore a pair is formed: the pixel gray level and the average of the neighborhood and each pair belong to a 2-dimensional bin. The resulting number of bins are $L*L$ [11]. The Resulting frequency f_{ij}, of a pair (i,j) divided by the total number of pixels in the image N, gives the Joint Probability mass function in 2-dimensional histogram given as:

$$P_{ij} = \frac{f_{ij}}{N}, \quad \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} P_{ij} = 1. \text{ [19]} \qquad \text{eq. (7)}$$

VI. RELATED WORK

A. *Image Segmentation Based on Refined Otsu Algorithms*

Zhong Qu and Li Hang [8] described 1D Otsu algorithm that is widely employed due to its uncomplicated computation and reliability. The 1D Otsu algorithms hardly evaluate the pixel's gray-level information disregarding the pixel's spatial neighborhood information resulting in poor segmentation. This algorithm ceases to function due to the variation of global distribution of the target and background. It yields better segmentation yet never works on image with two unequal classes. In this paper authors proposed a new method hinged on Entropy which imparts better result as compared to 1D Otsu algorithm.

B. *Comparative Analysis on Image Segmentation Algorithm*

W. X. Kang et.al [9] reviewed the ruling image segmentation algorithm and yields some worthy characteristics of image segmentation algorithm. The authors have classified Otsu algorithm as thresholding region based segmentation algorithm. The complexity rate of Otsu thresholding algorithm is extremely high and processing rate is exceptionally slow. The Otsu segmentation algorithm renders better segmentation results but to achieve accurate results, the algorithm needs to be integrated with other segmentation algorithm.

C. *Otsu Thresholding Based on Improved Histogram*

Z.Ningbo et.al [11] Presented a stable Otsu algorithm hinged on improved histogram in order to reduce the computation complexity of 1D and 2D Otsu algorithms. In this algorithm, a 2D histogram is projected on the diagonal and then applied to 2D Otsu to detect the optimal threshold value. In order to evaluate the practical performance of the proposed algorithm, Salt and pepper noise and Gaussian noise have been applied to image. The results prove that speed

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of thresholding is enhanced and is immune to noise for images with salt and paper noise yet not for Gaussian noise images.

D. *Otsu and K-Means Method*

L. Dongju and Y. Jian [13] reviewed that the key role of Otsu method is similar to that of K means method in multilevel thresholding. Both are based on the criteria of minimizing the within-class variance. Furthermore, the Otsu method deploys global thresholding while the K –Means employs local thresholding. The Otsu method requires a gray level histogram which is not true for K means. Both methods yield better segmentation results yet K -means imparts more satisfactory results rather than Otsu. Otsu method consumes more time and hence is more complex.

VII .CONCLUSION

The Otsu Algorithm for Image Segmentation has been detailed and described in this review along with its limitations. Furthermore an analysis regarding different ways of implementing Otsu algorithm with respect to their methods is carried out. Because of its simplicity Otsu algorithm is widely employed. Altogether several techniques are acceptable for countless Image applications and can be used for Object Recognition and Detection as well. However, no single method is enough for every image type and all methods are not worthy for a particular image type. Likewise the Basic OTSU Technique is not worthy for images under hazardous conditions. Hence to overcome this drawback an enhanced form of OTSU can be implemented in future by label uniformity.

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