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Fuzzy Entropy Based Approach to Image Thresholding

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Abstract*— Image thresholding plays very important role in many computer vision and image processing applications. Segmentation based on gray level histogram thresholding consists of a method that divides an image into two regions of interest; object and background. In image processing, we deal with many ambiguous situations. Fuzzy set theory is a useful mathematical tool for handling the ambiguity or uncertainty and provides a new tool to deal with multimodal histograms. In this paper, a novel image thresholding approach is proposed using fuzzy entropy. In the proposed approach, at first the input image is preprocessed to reduce noise without any loss of image details using fuzzy set theoretic approach. Then an optimal threshold is obtained from the preprocessed image using fuzzy entropy. The improvement of the proposed approach is discussed with the help of experimental results on different types of test images.

***Keywords*— Fuzzy entropy, Image segmentation, Noise removal, Thresholding, Uncertainty**

I. INTRODUCTION

Image segmentation aims to divide an image into homogeneous, self-consistent regions, which corresponds to different objects of the scene. It is the first step in image analysis. Image segmentation methods can be categorized into three techniques. The first technique is based on image thresholding, which classifies pixels of an image into two classes: foreground and background. The second method is based on abrupt changes in gray levels in order to detect isolated points, lines and edges in an image. The third method is to separate an image into different regions based on some desired criteria. In this paper, an image thresholding method is proposed using fuzzy entropy.

Thresholding is a fast, computationally simple, but effective image segmentation technique to separate objects from the background. There are different applications of image thresholding such as document image analysis, map processing, scene processing etc. The goal of thresholding is to select a threshold value that separates an image into two distinct graylevels. Thresholding is the transformation of an input image f to an output image g as follows:

$$g(x,y)=\begin{cases}1, & if \quad f(x,y)>T\\ 0, & if \quad f(x,y)\le T\end{cases}$$

where T is the threshold, $g(x,y)=1$ for image elements of objects and $g(x,y)=0$ for image elements of the background.

Selection of proper threshold is very crucial in threshold-based segmentation process. The value of the threshold can be obtained either in an interactive way or as a result some automatic threshold selection process. An image histogram, which defines the graylevel distribution of its pixels, is the key of the selection of the value of the threshold. A single global thresholds an image into objects and background. But this segmentation may not be satisfactory if objects contain different characteristic graylevels. In such cases, multiple local threshold values are required which can be applied over different areas of the image. This process of thresholding is known as multilevel thresholding using which different objects can be detected separately in an image. Determining such thresholds is a non-trivial task and its result is generally less reliable compared to its single-threshold counterpart.

In this paper, a fuzzy set theoretic approach is proposed to find a proper threshold value so that an image can be properly partitioned into meaningful regions. The process of thresholding becomes more complex when the image quality is not good, in other words, if the image contains any imprecision (of the gray levels) or ambiguity in some definitions (e.g. boundaries between the regions) or noise. The application of fuzzy set theory gained its importance in image processing in such situations. The nature of this fuzziness in the image therefore arises from the uncertainty present. When an image contains ill-defined regions, crisp segmentation should be avoided. The segments in that case may be viewed as fuzzy subsets of the image. In this paper, fuzzy entropy is used as an objective function which is optimized to obtain an appropriate threshold value. In fuzzy thresholding, an image is divided into two fuzzy sets corresponding to object and background regions by identifying membership functions associated with them.

The paper is structured as follows. Section 2 provides a brief literature review of selective existing techniques of image thresholding. A gentle overview of fuzzy entropy is provided in section 3 which is followed by proposed image thresholding scheme. Improvement of the proposed approach is discussed with the help of experimental results on various test images in section 4. Finally, conclusions are made in section 5.

II. LITERATURE REVIEW

Vision researchers have proposed and studied a number of excellent investigations on various thresholding techniques in the literature. Kittler and Illingworth [1] proposed the minimum error thresholding method assuming the normal distribution for both object and background which was improved by Cho et al [2]. Lee and Yang [3] determined the threshold value using Bayesian decision rule after estimating the parameters of normal distribution corresponding to the object and background from a truncated normal distribution. Pun [4] proposed a thresholding scheme based on the maximum entropy principle. Saha and Udupa [5] used an energy criterion based on intensity-based class uncertainty and region homogeneity to find the threshold by minimizing the energy. Otsu [6] suggested the threshold detection by maximizing the class separability based on within class variance, between class variance and total variance of gray levels.

Fuzzy set theory is a useful tool for partitioning of the image into meaningful regions using image thresholding. The nature and amount of the fuzziness in image may arise from the uncertainty present. Fuzzy clustering is one of the most important applications of the theory and is becoming popular in the recent years. Several researchers have investigated fuzzy set theory based thresholding techniques. Li et al. [7] combined the fuzzy set theory and information theory to obtain the threshold based on maximum fuzzy entropy. Chaira and Ray [8] [9] applied four types of methods, i.e. fuzzy divergence, linear and quadratic indices of fuzziness, fuzzy compactness and fuzzy similarity. These types of method minimize the fuzzy divergence or the separation between the actual and the ideal thresholded image. In [10], Tobias et.al introduced a method based on the similarity between gray levels which was to be minimized with the use of Zadeh's S-function. Jawahar et al applied fuzzy c-Means [11] and possibilistic c-Means [12] clustering for image thresholding by considering it as a two-class clustering problem. Pal and Rosenfeld [13] obtained optimal threshold using the concept of fuzzy compactness. They also used standard Zadeh's S-function for finding the membership values of the pixels in an image. Huang and Wang [14] obtained an optimal threshold using the entropy measure as a criterion function. Tizhoosh [15] classified fuzzy segmentation techniques into fuzzy thresholding, fuzzy rule, fuzzy clustering, fuzzy geometry and fuzzy integral based segmentation. Dutta et al [16] determined optimal threshold by minimizing normalized fuzziness function. In [17], more than 40 approaches of image thresholding were discussed and compared. Qiao et al [18] explored the knowledge about intensity contrast to derive a criterion for segmenting small objects.

III. PROPOSED APPROACH

A. Fuzzy Entropy

Fuzziness may result from the lack of crisp distinction between the elements belonging and not belonging to a set. Entropy is one of the measures of fuzziness that is often used and cited in the literature. The name entropy was chosen due to an intrinsic similarity of equations to the ones in the Shannon entropy. Basically, the Shannon entropy measures the average uncertainty in bits associated with the prediction of outcomes in a random experiment. The fuzziness measure based on the Shannon's function used in this paper is

$$f(A) = -\sum_{x}[\mu_A(x)\log_2 \mu_A(x) + (1-\mu_A(x))\log_2(1-\mu_A(x))] \qquad (1)$$

where $\mu_A(x)$ denotes the membership function of the fuzzy set A. Entropy measures the separation in an image that finds out the information of the two regions - above and below the threshold separately and calculates the entropy of the two classes. The entropies for all the gray levels below and above the threshold are added separately and then the entropy of the two classes is added to obtain the final entropy expression.

B. Noise Reduction

Two common types of noise that may be present in images are impulse noise and random noise. Out of these two, random noise is a more challenging type of noise which is to be reduced effectively. In the literature, there exist a significant number of linear and non-linear filtering methods for noise reduction in images. Linear filters cannot reduce impulse noise effectively and they often blur image edges. In such situations, nonlinear filtering like median filter is used. Recent progress in fuzzy logic allows the researchers to develop nonlinear noise reduction techniques using fuzzy logic reasoning with which the performance of noise reduction is improved significantly. In this paper, Gaussian fuzzy filter with median center is used to reduce image noise which is defined as

$$F[x(i+r, j+s)] = e^{-\frac{1}{2}\left[\frac{x(i+r,j+s)-x_{med}(i,j)}{\sigma(i,j)}\right]^2} \quad for\ r,s \in A \qquad (2)$$

where $x_{med}(i,j)$ and $\sigma(i,j)$ denote the median value and the standard deviation of all input values $x(i+r, j+s)\ for\ r,s \in A$ in the window A.

C. Proposed Algorithm

The objective of thresholding is to divide the image I into two regions – foreground (F) and background (B). For this purpose, the input image is fuzzified with the help of Gaussian membership function. For each intensity value t, the following criterion function $\phi(t)$ is designed based on Shannon's entropy measure which is to be minimized for optimal threshold.

$$\phi(t) = -\sum_{i=1}^{t}\mu_F(i)\log_2\mu_F(i) - \sum_{i=t+1}^{255}\mu_B(i)\log_2\mu_B(i) \qquad (3)$$

where μ_F and μ_B denote the fuzzy membership function for the foreground and background pixels respectively. The steps of the algorithm are given below:

1. Noise is reduced from the test images with the help of Gaussian fuzzy filter with median center as in (2)
2. Resultant image is fuzzified with the help of Gaussian membership function.
3. The criterion function $\phi(t)$ is designed for the fuzzified image by (3)
4. The optimal threshold t^* is obtained as

$$t^* = \min_t \ \phi(t), \ 0 \le t^* \le 255$$

IV. Results and Discussions

In order to evaluate the effectiveness of the proposed method, the proposed algorithm is tested and compared with two well-known global thresholding techniques, proposed by Otsu [6] and Kittler-Illingworth [1] and one relatively new technique, proposed by Huang and Wang [14] with the help of a number of images, but due to limitation of space, in this paper, the experimental results are shown for only four representative test images given in Figure 1.

Fig. 1 Representative Test Images (House, Tank, Lena, Cameraman)

It is observed from the figures Figure 2, 3, 4 and 5 that the proposed algorithm performs better than the two established thresholding techniques - Otsu's and Kittler-Illingworth's algorithms, and performs almost similarly (in fact, better for few test images) if we compare our algorithm with Huang-Wang's algorithm. However, in the presence of noise, the algorithm outperforms the three remaining algorithms considered in this paper.

Fig. 2 Thresholded image - House (Kittler-Illingworth, Otsu, Huang-Wang, Proposed)

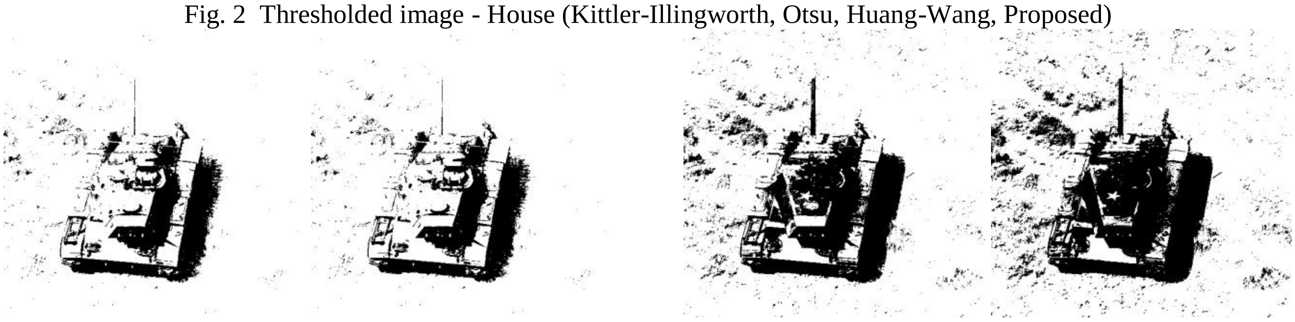

Fig. 3 Thresholded image - Tank (Kittler-Illingworth, Otsu, Huang-Wang, Proposed)

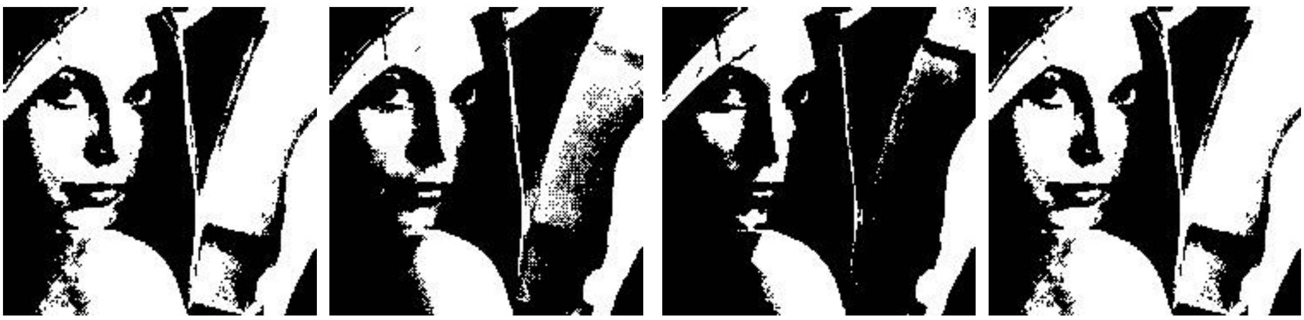

Fig. 4 Thresholded image - Lena (Kittler-Illingworth, Otsu, Huang-Wang, Proposed)

Fig. 5 Thresholded image - Lena (Kittler-Illingworth, Otsu, Huang-Wang, Proposed)

V. CONCLUSIONS

Grayscale image thresholding based on its histogram is considered as an effective tool for image segmentation. In this paper, a two-stage approach to image thresholding using fuzzy entropy is presented. It uses the measure of fuzziness based on Shannon function to evaluate the fuzziness of an image and to find an optimal threshold value. Fuzzy logic based methods to image thresholding consider the uncertainty in the image due to the imprecise pixel gray levels and vagueness in the image regions and boundaries which is incorporated in the form of membership function. Initially, an input image is preprocessed to noise reduction using a nonlinear fuzzy filter without affecting much image details and then a suitable threshold is determined with the help of a fuzziness measure as a criterion function. We demonstrated the effectiveness of our algorithm with the help of a number of test images. We shall try to extend this work to color images.

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