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# Performance analysis of image thresholding: Otsu technique

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ABSTRACT

Image thresholding is usually applied as an initial step in many algorithms for image analysis, object representation and visualization. Although many image thresholding techniques were proposed in the literature and their usage is well understood, their performance analyses are relatively limited. We critically analysed the feasibility of successful image thresholding under a variation of all scene parameters. The focus is based on Otsu method image thresholding technique since it is widely used in many computer vision applications. Our analysis based on Monte Carlo statistical method shows that the success of image segmentation depends on object-background intensity difference, object size and noise measurement, however is unaffected by location of the object on that image. We have also proposed a set of conditions to guarantee a successful image segmentation. Experiment using real-image data was set up to verify the validity of those conditions. The result demonstrates the capability of the proposed conditions to correctly predict the outcome of image thresholding using Otsu technique. In practice, the success of image thresholding could be predicted beforehand with the aid of obtainable scene parameters.

## 1. Introduction

Image segmentation is the process or technique of partitioning a digital image into several sets of pixels [1]. This segmentation process is the fundamental step for image analysis, object representation, visualization and other image processing tasks that is applied in various field of applications [2]. The main purpose of image segmentation is to simplify and/or change the respective image sample into an easily analysed image [3]. Thresholding method is the simplest and one of the most widely used techniques for image segmentation due to its simplicity [4]. The basic approach is to select an appropriate threshold value from a gray scale image. The purpose of thresholding is to separate the foreground of an image from its background [5–7]. Any pixel with an intensity value lower than the selected threshold value is considered to be region black part and vice versa [8]. Thus, thresholding is important in many applications such as industrial inspection, tracking, classification and detection [9].

Generally, thresholding techniques can be categorised into two classes which are global thresholding and local thresholding [10]. In global thresholding, a single threshold value is used to separate the foreground and the background of an image. While in local thresholding, a threshold value is assigned to each pixel to determine whether it is a foreground or background pixel using local information from the image [11]. Additionally, there is a number of thresholding algorithms already appeared in the literatures, and they can be broadly classified based on the information that they manipulate [25] – Histogram [38], clustering [39], entropy [14], object attribute [40], spatial [41] and local [42]. Even though the use as image thresholding is well understood and widely applied, their performance analyses are largely unaddressed. Thresholding performance also depends on a number of scene parameters, namely object-background intensity difference, noise measurement, size and position of the object.

For example, Fig. 1 shows the results of image thresholding using five different techniques [4]. Fig. 1(a) is the original grayscale image before undergoing image segmentation. Fig. 1(b) and (c) represent the successful cases of image segmentation while Fig. 1(d), (e) and (f) represent the unsuccessful cases of image segmentation using different thresholding techniques namely Otsu's, Hou's, Kapur's, minimum error and ground truth techniques [4]. It would be better if one is able to understand and analyse the parameters affecting the success of image thresholding. Then the success of image thresholding could be guaranteed and predicted beforehand based on those understanding.

The novelty of this paper mainly lies in the developing the conditions for successful thresholding using Otsu technique. The developed conditions enable one to predict the outcome of thresholding. Generally, in practice, we have a rough idea of the object-background

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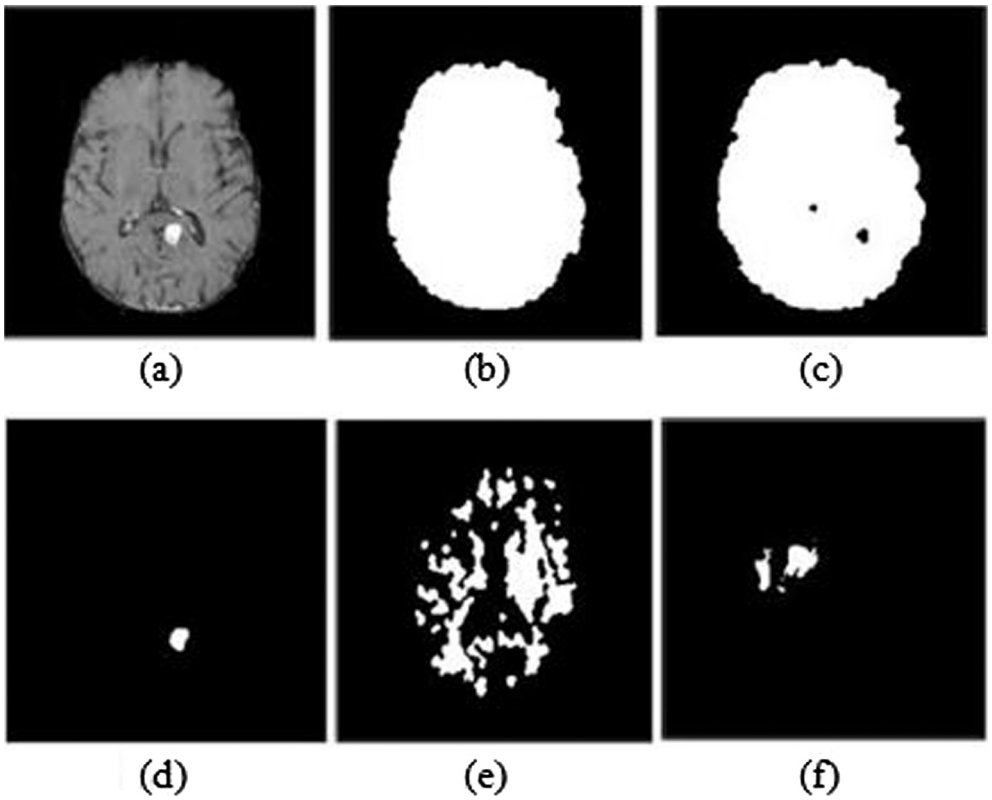


**Fig. 1.** Successfulness of the segmentation using different thresholding techniques. (a) Original grayscale image, (b) Otsu's techniques based threshold image, (c) Hou's techniques based threshold image, (d) Kapur's entropy techniques based threshold image, (e) Minimum error thresholding techniques based threshold image, (f) Ground truth techniques based threshold image.

intensity difference and object size which are the priori parameters associated with the performance of Otsu technique, thus we can predict the thresholding outcome beforehand. Therefore, these conditions serve as a guideline for practitioner in applying thresholding using Otsu technique.

## 2. Backgrounds and related works

Image thresholding is widely applied as an initial process in many computer vision algorithms. Even then, image thresholding is unable to exploit specific information or characteristics of the image. While human can easily differentiate an object from a complex background, it is somehow a difficult task for image thresholding to separate them [33]. Generally, thresholding techniques can be categorised into global thresholding and local thresholding. For global thresholding, a single stage threshold value is produced to separate an object from its background in an image. Meanwhile in local thresholding, thresholding is performed in one pass using local information obtained from the image [11]. However, global thresholding and local thresholding have its own weakness in certain image processing due to their inability to exploit information on the characteristics of their threshold images. In some cases, traditional technique is sufficient to segment the images as it treats all images in the same way.

In addition, Abutaleb [5], Brink & Pendock [13], Kapur et al. [14] and Pal & Pal [15] have proposed thresholding techniques based on entropy while Liang & Mao [7] and Pal & Rosenfeld [16] have proposed thresholding techniques using fuzzy approach. All of these methods are categorised as global thresholding technique.

There are also a number of techniques being proposed to solve local thresholding. Among the proposed techniques are intensity histogram of pixels in rectangular windows (proposed by Chow & Kaneko [17], Eilvil et al. [18] and Taxt et al. [19]), maximum and minimum intensities of pixels in rectangular windows (proposed by Bernsen [20]), mean and standard deviation of pixels in rectangular windows (proposed by Niblack [21]) and edge information (proposed by Parker [22] and Yanowitz & Bruckstein [23]).

The focus of this study is on Otsu thresholding techniques due to its simplicity, robustness and adaptability and one of the most applied thresholding algorithm is Otsu thresholding [12]. Otsu thresholding technique was proposed by Kittler and Illingworth (minimum error techniques) [6] and Nobuyuki Otsu [12]. Otsu thresholding techniques choose the optimal threshold by maximizing the between class variance of the gray levels in the object and background portions while Kittler and Illingworth minimum error technique approximates the histogram by a mixture of normal distributions and minimizes the classification of error probability [6,12]. These two methods have received compliments in many studies because of good performance on real images segmentation. Additionally, Otsu can be used and functions very well for thresholding if the implementation of noise removal and character recognition are properly done [11]. The advantage is the simplicity in calculating the threshold since the calculation involves 1D intensity data and this helps to reduce the computational processing time in real life application. Due to these advantages, a large number of methods have been proposed to improve the original Otsu's method, including [43,44]. However, these methods are usually unable to produce satisfying segmented results in case those images are riddled by noise.

Kalathiya and Patel had proposed the Otsu method with two different approaches which are iteration approach and custom approach [24]. During implementation, they had successfully showed that both of these approaches have given almost the same threshold value for segmenting image. The maximum result for between class variance of gray levels is defined as custom approach while the minimum result within class variance is defined as iterative approach [25].

The equation for within class variance (iterative approach) is shown in Eq. (1). Let $\sigma_W^2$ indicates the mathematical expression for within class variance, $\sigma_b^2$ is for the variance of the background pixels and $\sigma_f^2$ is for the variance of the foreground pixels. Additionally, $W_b$ and $W_f$ indicate mathematical symbols for weight of background and foreground, respectively.

$$\sigma_W^2 = W_b\sigma_b^2 + W_f\sigma_f^2 \tag{1}$$