Performance Analysis on the Effect of Noise in Inverse Surface Adaptive Thresholding (ISAT)

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Abstract. Thresholding is one of the powerful methods in segmentation phase. Numerous methods were proposed to segment the foreground from the background but there is limited number of studies that analyse the effect of noise since the present of noise will affect the performance of the thresholding method. In this paper, the main idea is to analyse the effect of noise in Inverse Surface Adaptive Thresholding (ISAT) method. ISAT method is known as an excellent method to segment the image with the present of noise. The result of this analysis can be a guideline to researcher when implementing ISAT method especially in medical image diagnosis. Initially, several images with different noise variations were prepared and underwent ISAT method. In ISAT method, several image processing methods were incorporated namely edge detection, Otsu thresholding and inverse surface construction. The resulting images were evaluated using Misclassification Error (ME) to evaluate the performance of the segmentation result. Based on the obtained results, ISAT performance is consistent although the noise percentage increases from 5% to 25%.

1. Introduction

Thresholding is the oldest, simple, yet a powerful method to distinguish the objects from the background and is widely used in various applications. Thresholding segments a pixel based on the value of its intensity or other attributes in comparison with the threshold and thus it is computationally inexpensive and fast. However, various contributing factors may complicate the thresholding process such as, non-stationary and correlated noise, inadequate contrast and varying illumination. Thresholding can also be regarded as a transformation of an input image f(i,j), to an output segmented binary image Output (i,j) as denoted in equation (1);

\[
Output(i,j) = \begin{cases} 
0 & \text{if } f(i,j) \geq T \\
1 & \text{if } f(i,j) < T 
\end{cases}
\]  

where T is the threshold value, Output (i,j) = 1 represents the background and Output (i,j) = 0 represents the object or vice versa [1]. The crucial part of thresholding lies in the selection of an
appropriate threshold value, \( T \). Consequently, numerous researchers have improved the original thresholding scheme by introducing various strategies to help identify and calculate the threshold and thus improve the detection process [2-4].

Global thresholding is defined as the use of a single threshold to segment the entire image. Local thresholding is similar to global thresholding, however it only applies to subimages instead of the entire image. The threshold for each subimage is determined independently in local thresholding. However, if a subimage's threshold cannot be determined, it can be interpolated from neighbouring sub-images. Adaptive thresholding is the process of segmenting an image using a variable threshold that varies from pixel to pixel. In the literature, there are several publications on thresholding approaches, and two comparison studies are offered by Sahoo et al. [5] and Sezgin and Sankur [6]. Thresholding-based techniques can be divided into six categories, according to [6]. Figure 1 illustrates the taxonomy of thresholding approaches.

![Figure 1. The taxonomy of the thresholding-based method](image)

In this paper, the main focuses to analyse the effect of noise in Inverse Surface Adaptive Thresholding (ISAT). ISAT was introduced in 2012 that implemented in standard image and several applications such as diabetic retinopathy detection and weld discontinuities segmentation [7-8]. The ISAT method was implemented without any pre-processing and post processing approach. The ISAT method is categorized under local adaptive method, and it will produce a threshold for each of the pixel. There are similar studies that analyse the performance of thresholding methods such as Otsu thresholding [10-11]. In this paper, the focus is to analyse the ISAT performance with different noise variations. Section 2 presents the ISAT algorithm and Section 3 presents the results and discussion. Lastly, the conclusion is presented to conclude the finding.

2. Inverse Surface Adaptive Thresholding (ISAT) Segmentation

Inverse Surface Adaptive Thresholding (ISAT) was introduced in 2012 and has been implemented in several applications [7-8]. ISAT is categorized under local adaptive method since it will produce different thresholds based on its neighbours’ information. The flow of the proposed analysis process is illustrated in Figure 2.

To begin, edge detection is applied to the image in order to determine the object boundaries [12]. Because of their simplicity and convenience of implementation, standard Prewitt operators are chosen. The image is convolved with the four Prewitt operators at each pixel to capture the edge directions in horizontal, vertical, diagonal, and anti-diagonal orientations. The absolute values of the four convolutions are compared, and the highest value is selected to represent the pixel's edge information. The edge image, abbreviated \( Ed \), is made up of these gradient values \((i,j)\). The gradients (or edge values) of pixels at the object's perimeter are expected to be higher than the gradients of pixels in the object's background and interior. In \( Ed(i,j) \), a threshold is needed to differentiate the weak edges from the strong edges in order to distinguish the pixels at the object borders from the others. Pixels with values less than the threshold are assigned to the weak edge group in \( Ed(i,j) \), while the rest are
assigned to the strong edge group. The Otsu [13] method is used to prevent manually selecting a threshold value that could be affected by uneven light and contrast. It automatically determines a threshold value.

![Figure 2. Block diagram of the proposed approach](image)

The intensities and gradients of the original image I(i,j) and those of the negative image N(i,j) are used to create the inverse thresholding surface T(i,j), which is created by subtracting I(i,j) from the maximum intensity level L. T(i,j) requires the interpolation of pixel values in eight passes, with the difference between each pass being used to process the pixels. The pseudocode of the ISAT is denoted in Figure 3.

![Figure 3. The pseudocode of the ISAT algorithm](image)

In spite of the encouraging results obtained from the implementation of the ISAT, the effect of noise when implementing the method is yet to be analysed. In this paper, several noise variations are
tested with ISAT segmentation. The misclassification error (ME) criterion was adopted to measure the performance of the results. The ME equation is denoted in equation (2).

\[
ME = 1 - \frac{|B_o \cap B_T| + |F_o \cap F_T|}{|B_o| + |F_o|}
\]  

(2)

Bo and Fo indicate the background and foreground of the error-free source image, respectively, whereas B_T and F_T denote the background and foreground of the segmentation results. The ME calculates the percentage of background that is misclassified as foreground, as well as the proportion of foreground that is misclassified as background. This can range from 0 for a fully categorised image to 1 for a binarized image that is completely incorrect.

3. Results and Discussion
In this paper, several images were constructed with different noise variances. The noise is added using GIMP software with randomized noise of 5%, 10%, 15%, 20% and 25%. The noise has been set to 25% because the object cannot be seen clearly if the noise percentage is increased. The purpose of this study is to analyse the ability of ISAT to segment objects. Three standard images and one retinal image were utilised. This experiment was implemented using Matlab 2018a and ran on Intel Core i7-6700HQ 2.60 GHz processor.

Figure 4 shows the sample of original images and its ground truth and Table 1 shows the resulting image after implementing ISAT method.

![Sample Images](image-url)
Figure 4. Original image (a) (c) (e) (g) and Ground truth image (b) (d) (f) (h)

Table 1. Segmentation result for different noise percentage

| Noise Percentage | Original Image with noise | Segmented image using ISAT |
|------------------|---------------------------|-----------------------------|
| 5                | ![Image](image1.png)      | ![Image](image2.png)        |
| 10               | ![Image](image3.png)      | ![Image](image4.png)        |
| 15               | ![Image](image5.png)      | ![Image](image6.png)        |
Table 2 shows the ME result for the tested images. As we can see from the Table 2, when the noise increases the ME value also increase. The ME value nearly to 0 indicates a good segmentation result. However, the increment is small even when the noise percentage is increased. This is due to the ISAT method capable to segment the object although the image suffers with noise. Since the ISAT method utilizes gradient information to obtain the edges of the object and Otsu method will remove the weak edge, most of noise will not be considered except the strong noise pixels.

| Noise variation (%) | 5        | 10       | 15       | 20       | 25       |
|---------------------|----------|----------|----------|----------|----------|
| Simulated image     | 0.381837 | 0.388469 | 0.391531 | 0.393776 | 0.39898  |
| Coin                | 0.354005 | 0.364988 | 0.375062 | 0.383072 | 0.391825 |
| Flower              | 0.202213 | 0.300849 | 0.319351 | 0.328138 | 0.339205 |
| Retina              | 0.260816 | 0.275765 | 0.286888 | 0.303520 | 0.310051 |

4. Conclusion
ISAT method utilizes gradient information to construct the inverse surface and then binarized the image. ISAT also incorporate several methods such as edge detection and Otsu thresholding. Edge detection was used to obtain the edges of the object and Otsu thresholding was used to remove the weak edges obtained by edge detection. By removing the weak edges, several noise pixels were removed as well. This is one of the important criteria for ISAT. Based on the results obtained, when the noises increase the ME results increase but the result of ME is quite consistent although the noises increase. In future, the consistency of this finding can be tested using more images with different noise variations, the effect of size of the object, location of the object and intensity different between the object and background.

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