An In-Depth Investigation Into The Effects Of Thresholding Techniques On Grayscale Images

Dr. Rajeev Kaushik[1*]

[1*]Department of Computer Science and Engineering, R D Engineering College, India

***Corresponding Author:** Dr. Rajeev Kaushik
*Email:- kau6700@gmail.com

Abstract
This communication presents an extensive survey of diverse image thresholding techniques applied to a standardized dataset of five 256x256 grayscale images. The evaluated methods include mean thresholding, histogram thresholding, edge thresholding, variable thresholding, and P-tile thresholding. Each technique's algorithm parameters are meticulously optimized to cater to the specific characteristics inherent in each image. This survey emphasizes the critical role of selecting appropriate thresholding techniques tailored to specific image characteristics and application requirements. Histogram thresholding emerges as a preferred method due to its consistent ability to achieve superior BPR results. Continued research efforts are crucial for advancing thresholding methodologies and expanding their applicability across diverse fields, such as study of medical images, remote sensing, and industrial quality control.

Introduction

Thresholding is an effective method for object-background separation in images [1]. The process of image segmentation involves dividing an image into homogeneous regions, often to highlight specific features such as lines and curves. In this context, each pixel in the image is evaluated for similarity based on certain properties like color, intensity, or texture. Numerous algorithms have been developed for image segmentation, primarily based on two main properties: intensity value discontinuity and similarity. Due to its computational efficiency, thresholding is a preferred technique in machine vision applications and is widely employed for image segmentation [2].
Threshold segmentation techniques can be classified into three categories:

1. **Local techniques**: These basically depend on the local properties of the pixels and their immediate surroundings.
2. **Global techniques**: These utilize globally gathered information to segment the image.
3. **Split, merge, and growing techniques**: These methods use the concepts of homogeneity and geometrical contiguity to achieve better segmentation results.

A thresholding method known as the auto-adaptive approach, which is based on multi-resolution analysis (MRA), is utilized to reduce the complexity of 2-D histograms. This approach enhances the precision of multi-resolution threshold searching. These methods originate from the advanced segmentation results achieved by 2-D histograms, which leverage the spatial correlation of gray levels and the flexibility and efficiency of multi-resolution threshold segmentation techniques [3].
In global thresholding, the threshold is determined solely by gray level values, reflecting the characteristics of individual pixels. Conversely, local thresholding involves dividing the original image into multiple sub-regions, with distinct threshold values selected for each sub-region to accommodate local variations in pixel characteristics [4].
Moreover, the auto-adaptive MRA-based method improves segmentation accuracy by dynamically adjusting to the image's content, making it particularly effective in handling complex images under different lighting conditions and textures. This method also leverages inherent multi-resolution capabilities, enabling it to process images at various scales and resolutions. This is essential for applications that demand high precision and robustness in image analysis.

Literature Survey

Preliminary studies utilizing fuzzy logic for image segmentation have been documented in the literature. An ideal segmentation method should achieve a classification rate of 100% and a false detection rate of 0%. However, adapting segmentation techniques to various color images remains a challenging task [5]. Recently, data fusion techniques have been explored for medical image segmentation. Data fusion combines diverse data from multiple sources to derive an optimal set of objects for investigation.. A key advantage of data fusion is its ability to handle uncertain, imprecise, and incomplete information [6]. Thresholding is a fundamental technique in image processing used to convert a grayscale image into a binary image. This process significantly impacts subsequent steps, such as document segmentation into text objects and the accuracy of Optical Character Recognition (OCR) [7]. Inappropriate thresholding can lead to defects such as blotches, streaks, erasures, and fractures in character shapes within the document. In Non-Destructive Testing (NDT) applications, thresholding often serves as the initial step in a sequence of processing operations, including morphological filtering, measurement, and statistical assessment [8]. Unlike document images, which form a specific category, NDT images originate from various modalities with differing application goals, making it difficult to predict a universal thresholding method suitable for all NDT cases.

Several survey papers have addressed thresholding methods. Lee, Chung, and Park [9] performed a comparative analysis of five global thresholding methods and proposed several criteria for evaluating thresholding performance. Histogram shape-based methods analyze the peaks, valleys, and curvatures of the smoothed histogram to achieve thresholding based on histogram shape properties. These methods generally look for two major peaks and an intervening valley using tools like the convex hull of the histogram, curvature analysis, and zero crossings of wavelet components. Other approaches approximate the histogram using two-step functions or two-pole autoregressive smoothing.

Moreover, advancements in thresholding techniques have led to the development of adaptive and hybrid methods that combine the strengths of various traditional methods. These innovative approaches enhance the reliability and precision of segmentation, particularly in complex imaging scenarios such as multi-modal medical imaging and industrial inspection. The ongoing research in this domain aims to refine these methods further, addressing limitations and improving their applicability across diverse image processing tasks.

METHODOLOGY

This section focuses on the development and implementation of various thresholding algorithms to determine the ideal value of threshold for image binarization. Detailed algorithms for different thresholding methods are outlined.

Algorithm for Mean Thresholding:

The mean thresholding method involves calculating the average pixel value to serve as the threshold. The procedure includes the following steps:

1. **Calculate the Sum of Pixel Values**: Compute the total sum of all pixel values in the image.
2. **Count the Number of Pixels**: Determine the total number of pixels in the image.
3. **Compute the Threshold Value**: Use the formula t= sum of pixel value/ sum of pixels (using 2 & 3).
4. .**Binarize the Image**: Apply the calculated threshold value to convert the grayscale image into a binary image.

This threshold value is applied uniformly across the entire image to produce a binary image.

Algorithm for Histogram thresholding:

In histogram thresholding, various methods exist for determining the optimal threshold value. For this discussion, we focus on the mid-point method. The steps involved are as follows:

1. **Initial Threshold Determination**: Select an initial threshold value, t.
2. **Calculate Mean Values**: **m1:** Compute the mean pixel value for all pixels below the threshold (t). , **m2:** Compute the mean pixel value for all pixels above the threshold (t).
3. **Compute New Threshold**: Calculate the new threshold value, t_n= (m1+m2)/2
4. **Threshold Stabilization**: If the threshold value has stabilized ($t = t_n$), the current threshold value t is considered final. If not, update t to t_n and repeat from step 2.

This iterative process continues until the threshold value stabilizes, providing a consistent threshold for binarizing the entire image.

Algorithm for Variable thresholding:

In variable thresholding, the threshold value is adapted for each pixel based on local image characteristics. This method, also known as adaptive thresholding, ensures that varying lighting conditions and local contrast differences are accounted for. The algorithm follows these steps:

1. **Divide the Input Image**: Segment the input image into multiple sub-images p1,p2,p3,…, p8
2. **Select Sub-image**: For example, take p1=I(1:32,1:256)
3. **Calculate Sum of Pixel Values**: Compute the total sum of all pixel values within the sub-image.
4. **Calculate Number of Pixels**: Determine the total number of pixels within the sub-image.
5. **Compute Threshold Value**: Calculate the threshold value for the sub-image using t=sum of pixel value / number of pixel.
6. **Binarize Sub-image**: Apply the calculated threshold value to convert the grayscale sub-image into a binary sub-image.
7. **Repeat for All Sub-images**: Repeat steps 3 to 6 for all sub-images.
8. **Combine Binary Sub-images**: Merge all the binary sub-images to form a single binary image.

Algorithm for Edge thresholding:

In the edge thresholding method, object boundaries within an image are detected through a series of steps involving image smoothing, gradient computation, and thresholding. The detailed steps are as follows:

1. **Image Smoothing with Gaussian Filter**: Apply a Gaussian filter to smooth the image, reducing noise and minor details. This is represented as $g(x, y) = G(x,y)*i(x,y)$ where G(x,y) is the Gaussian kernel and i(x,y) is the input image.
2. **Gradient and Magnitude Computation**: Compute the gradient components $g_x(x, y)$ and $g_y(x, y)$ of the smoothed image. Calculate the gradient magnitude M(x,y) using $M(x,y) = sqrt (g_x2(x,y)+g_y2(x,y)$
3. **Direction Computation**: Determine the gradient direction θ (x, y) using $\theta (x, y) = \tan^{-1} (g_y(x, y) / g_x(x, y))$.

4. **Initial Thresholding**: Apply an initial threshold to the gradient magnitude image M(x, y) to highlight potential edges.
5. **Non-Maxima Suppression**: Suppress non-maxima pixels in θ (x, y) to thin the edges, retaining only the local maxima in the gradient direction.
6. **Double Thresholding**: Apply two thresholds T1 (high) and T2 (low) to the gradient magnitude image to classify strong, weak, and non-edges, resulting in two binary images.
7. **Edge Linking**: Link edge segments to form complete edges, connecting weak edges to strong edges if they are contiguous, ensuring coherent edge detection.

Algorithm for P-tile thresholding:

The process of setting a threshold in image processing involves determining an optimal intensity level to distinguish between different regions in an image. The steps are as follows:

1. **Set Initial Threshold**: Determine an initial threshold value by identifying the intensity level in the image.
2. **Calculate Grey Level Using Histogram**: Compute the grey level using the histogram value H(g), which represents the frequency distribution of pixel intensities.
3. **Percentage Intensity Calculation**: Ensure that P% of the pixels have intensity levels less than the determined grey level. This step involves cumulative histogram analysis to find the intensity level that satisfies this condition.
4. **Neighborhood Examination for Optimal Threshold**: To identify the optimal threshold, examine the histogram H(g) in the neighborhood of the current grey level g. This involves analyzing the local histogram characteristics to fine-tune the threshold value.

RESULTS

The objective of this research is to evaluate and compare various thresholding techniques to identify the most effective method. The study utilizes a grayscale bird image with dimensions of 256x256 pixels as the standard test image. The evaluation parameter used is the Black Pixels Ratio (BPR), which quantifies the ratio of black to white pixels after applying each thresholding technique. The methods compared include Mean thresholding, Histogram thresholding, Variable thresholding, Edge thresholding, and P-tile thresholding. The comparison of thresholding techniques aims to identify the method that yields the highest BPR, indicating superior image binarization capability. The BPR metric provides quantitative insights into the effectiveness of each technique in accurately segmenting the bird image into foreground (black) and background (white) regions. Results are presented to facilitate informed decisions regarding the optimal thresholding approach based on the specific requirements of image processing applications, such as document analysis, medical imaging, and industrial inspection.

Bird image:

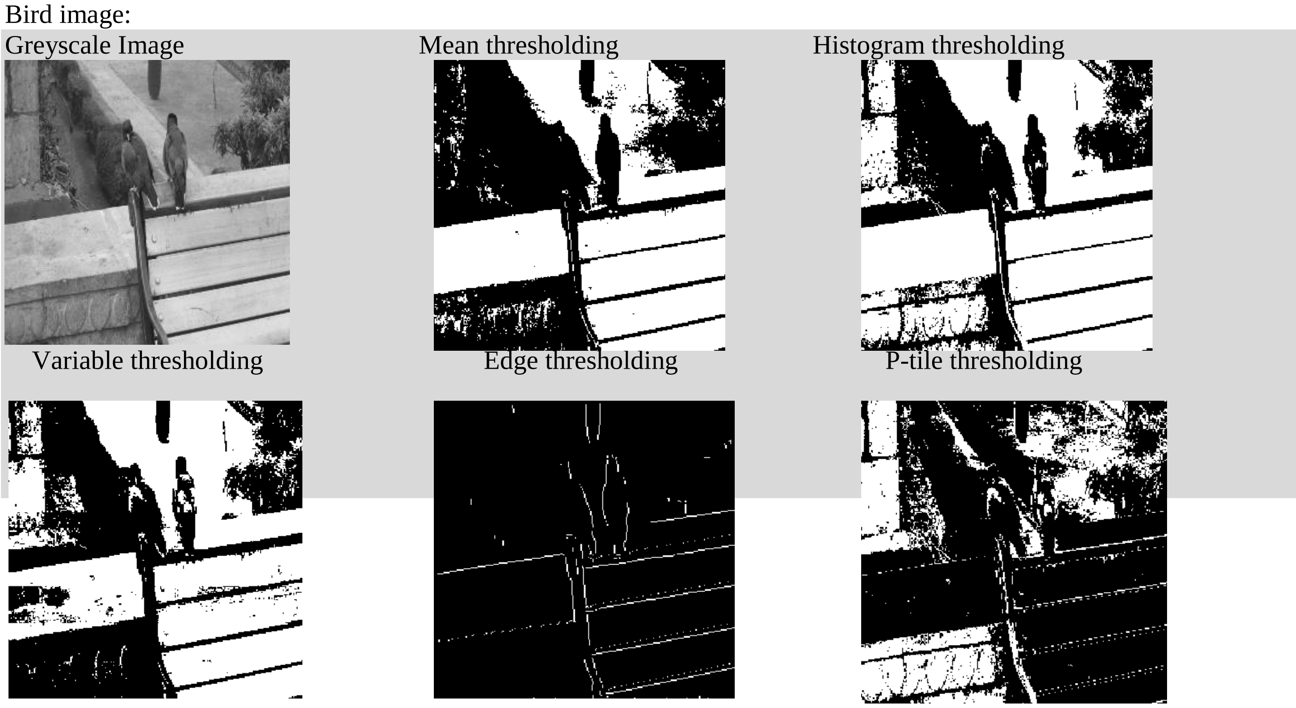

Figure 1 Comparison of bird image

Thresholding techniques	Black to white pixel ratio	BPR (%AGE)
Mean thresholding	131366:130778	50.11
Histogram thresholding	24660:237484	36.12

Edge thresholding	224499:37645	97.94
Variable thresholding	107002:155142	46.14
P-tile thresholding	80919:181225	73.25

Table 1 Comparison of thresholding techniques for bird image

From above table we can investigate that Edge Thresholding appears to be the best choice among the given techniques for this specific task, as it achieves the highest BPR percentage, indicating superior performance in segmenting objects based on their edges or boundaries.

Conclusion

This paper presents a structured survey of various image thresholding techniques categorized based on their applications and methodologies. The evaluation is conducted using a set of five grayscale images, specifically a bird image sized at 256x256 pixels, to analyze the strengths and weaknesses of each method. The primary metric used for performance assessment is the Black Pixels Ratio (BPR), where a lower number of black pixels indicates a better binary image quality. The survey underscores the importance of selecting appropriate thresholding techniques based on specific application needs and image characteristics. While Histogram Thresholding emerges as the preferred method in this study for its superior BPR results, ongoing research efforts are essential to further refine thresholding algorithms for enhanced image processing capabilities.

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