Experimental Analysis of Image Segmentation Using Thresholding Techniques

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Abstract- Image segmentation is a critical step in computer vision, enabling the separation of objects from the background for further analysis. Thresholding is one of the simplest and widely used segmentation techniques due to its computational efficiency and ease of implementation. This experimental study investigates the performance of global and adaptive thresholding methods for segmenting real-world images, including traffic signs and vehicle plates. MATLAB and Python (OpenCV, TensorFlow) were used for implementation. The study evaluates the methods based on accuracy, precision, recall, F1-score, and Intersection over Union (IoU). Experimental results demonstrate that adaptive thresholding significantly outperforms global thresholding in complex scenes with varying illumination, shadows, and noise, while also highlighting the benefits of post-processing with morphological operations.

1. INTRODUCTION

Segmentation is a fundamental process in image analysis, where an image is partitioned into meaningful regions. Thresholding techniques classify pixels based on intensity values, separating foreground from background. Despite the emergence of deep learning methods, thresholding remains important due to its simplicity, speed, and interpretability, especially for applications with limited computational resources. Traffic sign detection, license plate extraction, and industrial defect detection are examples where thresholding can serve as a fast and effective segmentation approach.

This experimental study focuses on evaluating global and adaptive thresholding methods on real-world images. The aim is to analyze the effectiveness, robustness, and limitations of each method, and to provide insights into practical implementation strategies.

2. LITERATURE REVIEW

Thresholding-based segmentation has been extensively studied for decades. Global thresholding methods, such as Otsu's algorithm, select a single threshold to maximize inter-class variance, which works well for high-contrast images with uniform backgrounds. However, in real-world applications, lighting variations and shadows reduce performance. Adaptive thresholding methods calculate thresholds locally for image subregions, allowing better segmentation under non-uniform illumination. Recent studies have combined thresholding with morphological operations to refine boundaries and remove noise. Furthermore, hybrid approaches integrate thresholding with deep learning models, where probabilistic maps predicted by a CNN are converted into binary masks using thresholding, enhancing segmentation accuracy in complex scenarios.

3. METHODOLOGY

3.1 Dataset

Two datasets were used for experiments:

1. Traffic Sign Dataset: 500 images containing various traffic signs captured under daylight, shadows, and night-time conditions.
2. Vehicle License Plate Dataset: 400 images with different plate formats, lighting conditions, and partial occlusions.

All images were resized to 256×256 pixels for uniform processing.

3.2 Preprocessing

Preprocessing aimed to enhance image quality and simplify segmentation. Steps included conversion to grayscale, Gaussian filtering to reduce noise, and histogram equalization to improve contrast. Region of interest (ROI) masks were applied to focus on areas containing traffic signs or license plates.

3.3 Thresholding Techniques
Global Thresholding:
A single threshold was computed for each image using Otsu's method. Pixels above the threshold were classified as foreground, and those below as background.

Adaptive Thresholding:
Thresholds were computed locally using mean and Gaussian-weighted neighborhoods. This method adapts to illumination changes, improving segmentation accuracy for images with shadows or glare.

3.4 Post-Processing
Morphological operations such as erosion and dilation were applied to remove small noise regions and refine segmented objects. Connected component analysis was used to isolate individual signs or characters in the segmented output.

3.5 Evaluation Metrics
Segmentation performance was evaluated using:

- Accuracy – percentage of correctly classified pixels.
- Precision – ratio of true positive pixels to all predicted positive pixels.
- Recall – ratio of true positive pixels to all actual positive pixels.
- F1-score – harmonic mean of precision and recall.
- Intersection over Union (IoU) – overlap between predicted and ground-truth masks.

4. EXPERIMENTAL SETUP

Experiments were implemented in MATLAB R2023b and Python 3.11 using OpenCV and NumPy libraries. Adaptive thresholding was tested with different block sizes and constants to optimize performance. Post-processing parameters were fine-tuned for best visual and quantitative results. Each image was processed individually, and results were averaged across the datasets

5. RESULTS AND DISCUSSION

Method	Accuracy (%)	Precision	Recall	F1-score	IoU (%)
Global Thresholding	82.4	0.81	0.80	0.805	70.5
Adaptive Thresholding	94.6	0.93	0.95	0.94	88.7
Adaptive + Morphology	96.1	0.95	0.96	0.955	90.3

Table 1: Classification Report

The results demonstrate that adaptive thresholding significantly improves segmentation performance over global thresholding, particularly in images with non-uniform illumination. Incorporating morphological operations further enhances object boundary refinement and reduces false positives. Global thresholding is faster computationally but struggles with shadows, glare, and partially occluded objects. Visual inspection confirmed that adaptive thresholding accurately segments traffic signs and license plate characters under diverse real-world conditions.

Challenges observed include extreme lighting conditions at night and heavy occlusions, where even adaptive thresholding occasionally misclassified background pixels. Optimizing block size and thresholding constants is crucial for achieving high-quality results.

6. CONCLUSION

This experimental study highlights the effectiveness of thresholding-based segmentation for real-world images, emphasizing adaptive thresholding combined with post-processing. While global thresholding provides a computationally efficient approach, it is insufficient under variable lighting conditions. Adaptive thresholding addresses this limitation and, when combined with morphological operations, delivers high segmentation accuracy and boundary precision.

Future work may explore integration with deep learning models for automated threshold selection, real-time segmentation for autonomous vehicles, and evaluation under extreme environmental conditions. Thresholding remains a valuable tool for rapid and reliable segmentation in computer vision applications.

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