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Performance Metrics for Image Segmentation Techniques: A Review

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ABSTRACT
Image Segmentation has become a lot popular in recent years because of its application in computer vision and related field. This has led to an upsurge in different segmentation techniques from the research community. Different image segmentation techniques have their strengths and weaknesses and some are more geared to some specific application. The need to evaluate the performance of these techniques became necessary because of the autonomous system that do quite a lot of these segmentation. This paper reviews different types of metrics used for evaluating the performance of different image segmentation techniques. It was found out that some metrics are used by some specific image segmentation techniques and their strength and weaknesses are outlined.

Keywords: *Image, segmentation, performance, metrics*

1. INTRODUCTION

Image segmentation is an important step in the processes of Digital Image Processing (DIP). It is usually sandwiched between image pre-processing and image recognition stage. There are different techniques of image segmentation, these techniques include but not limited to clustering methods [1], thresholding methods [1], edge detection [1], region based methods [1], partial differential equations (PDE) [2] and artificial neural network (ANN) [2]. These methods can be largely divided into pixel-based methods (where pixels with similar features like color and texture are clustered) region-based methods (where pixels are clustered according to their similarities and spatial connectedness) and boundary-based methods (use pixels around the boundary of an object to define it).

Various Image Segmentation techniques have their advantages and disadvantages and some are more suitable for some applications than others. There is no comprehensive and standardized report for image segmentation evaluation metrics that can be used by evaluators. Since most of these performance measures are application dependent, naive evaluators can use the wrong metrics for the wrong application thereby giving inaccurate result. There is need to identify these metrics for measuring the performance of the different image segmentation techniques. This can be achieved if these metrics from the literatures can be thoroughly discussed, organized and summarized. Moreover, the strengths, weaknesses, adequacy and correctness of each of these metrics will be brought to light for image segmentation evaluators to make informed decisions while making use of them.

The outline of this paper is as follows: Section 2.1 gives an overview of Image Segmentation techniques. Section 2.2 discusses some of the Image Segmentation Evaluation Techniques while section 2.3 describes the performance metrics used for by the evaluation methods. Finally, conclusions are drawn in section 4. .

2. METHODOLOGY

2.1 Image Segmentation Techniques

The two main objectives of Image Segmentation are to decompose image into parts for further analysis and to perform a change of representation, which involves organizing the pixels of the image into higher-level units that are either more meaningful or more efficient for further analysis [3].

This makes image segmentation a central part in digital image processing for computer visions, robotic navigation, content-based image retrieval and etc. There exist lots of image segmentation algorithms and the list can barely be exhausted. From the more traditional threshold method [1], clustering method [1], gradient based methods [2], region-based methods [1], gray histogram methods [2], graph partitioning methods to more recent algorithms like the Mean Shift Segmentation[4], Modified Recursive Shortest Spanning Tree (MRSST) [4], Normalized-cut method (NC) [5], Efficient graph-based method (EG) [5], Ratio-cut method (RC) [5].

With the numerous number of image segmentation techniques in existence, there have been several efforts to categorize them into different groups. Based on the criteria used for the groupings, the groups are not mutually exclusive hence some segmentation algorithms can be found under more than one category. Table 1 shows some of the grouping of image segmentation techniques found in the literature.

Table 1: Different Categorizations of Image Segmentation Techniques

Segmentation Techniques Categorization	
Category A from [6] phylosophical	a)Edge based b) Point/Pixel based c) Region based and d) Hybrid approach
Category B from [7]	a) Color based b) Texture based algorithms.
Category C From [8]	a) Classical and targeted segmentations b) Segmentation based on minimizing a piecewise-smooth Mumford-Shah functional on a graph c) Segmentation based on active contours without edges d) Random walks algorithm based segmentation e) Segmentation of non-homogenous regions of an image based on an energy fitting minimization f) Segmentation of non-homogenous regions of an image based on the level sets method
Category D from [4]	a) Mean Shift Segmentation (MS) b) Region Based Automatic Segmentation (RBAS) c) Modified Recursive Shortest Spanning Tree (MRSST) d) Spatio Temporal Video Segmentation (SEG2DT)
Category E from [1]	a) Clustering. b) Edge Detection, c) Multiple Thresholding and d) Region-Based
Category F from [9]	a) Seeded Region Growing b) Interactive Segmentation Using Binary Partition Trees

The first category consists of well-known classification for image segmentation techniques. These techniques include finding out the edges or boundary of an object. Chain-code is an example of a method that can be used for determining the edge or boundary of an object. Region growing method involves initial selection of seed points where neighbouring pixels are examined to determine if they belong to that region. Region based method is sometimes referred to point based image segmentation because an initial selection seed point is needed Hybrid method uses the combination of two or more types of the segmentation methods. A combination of region-based and edge-detection methods is an example of hybrid method. Another major classification of Image segmentation is color-based and texture based segmentations. These methods are categorized under second category. While the former groups pixels based on their color, the latter groups the pixels based on their textures.

The categories C and D are some examples of hybrid methods of image segmentation discussed previously. Most of them are developed for some specific applications. Category E as described by [1] involves segmentation methods like clustering, edge-detection, thresholding and region-based. Clustering is an unsupervised method of data analysis and is broadly divided into partitioning and hierarchical methods. Example of clustering algorithms include the K-means algorithm, Fuzzy C-means algorithm (FCM), the Expectation Maximization algorithm, Minimum Spanning Tree (MST) algorithm and etc

2.2 Image Segmentation Evaluation Techniques

Recently, there have been lots of interests in evaluating image segmentation techniques. Motivation for this is due to optimizing the existing techniques. Thus evaluation techniques are developed to aid embedded/autonomous system make the choice of the best segmentation method to apply for a particular image. Though no single approach can be said to be the best, some methods perform better for some images than others.

Zhang et al. in [10] broadly divided the segmentation evaluation techniques into Subjective evaluation and Objective evaluation depending on whether human being has evaluated the image visually or not. Subjective evaluation is the most common form of evaluation method where a human compares the segmentation results from different segmentation algorithms. On the other hand, Objective evaluation can further be divided into supervised and unsupervised methods. Supervised method requires access to ground truth segment (manually segmented reference image) while the unsupervised method does not require access to the ground truth.

The most traditional and common metrics used in performance analysis of different image segmentation techniques is the subjective methods. This means that a segmented image is compared with the original image by human inspection. However, this method is so cumbersome that it cannot be used for large number of images; more so different humans can rate the performance differently because human interpretation can be highly subjective. With the advent of more independent metrics like mean square error, entropy, color difference between regions and etc [10], the need to review these metrics became necessary.

Another categorization of image segmentation evaluations according to [4] are the theoretical and experimental. The experimental can be further divided into feature based and task based. Feature based is then divided into one with ground truth and one without ground truth.

3. RESULTS AND DISCUSSIONS

3.1 Performance Metric for Image Segmentation Algorithms

There are presently lots of unsupervised evaluation methods of image segmentation these include F', D_{WR}, E_{CW}, Busy, SE, SM and etc [10]. These evaluation methods are based on metrics like color error, metrics based on squared color error, metrics based on texture, metrics based on entropy, metrics based on average color between regions, root mean square error, metrics based on difference of color along local boundaries, metrics based on barycentre layout and metrics based on layout entropy [10].

Different researchers have been creating different metrics to objectively evaluate image segmentation algorithms, among which are Normalized Probabilistic Rand (NPR) by [12], metric based on the distance between segmentation partitions proposed by [13] and etc. Many of the performance metrics applied to large set of images shows that some of the metrics suffer from under-segmentation bias while others suffer from over segmentation bias.

Some other unsupervised evaluation criteria of segmentation results had been compared in the work of [11] namely: Zeboudj, Inter, Intra, Intra-inter, Borsotti and Rosenberger. Intra-region uniformity metrics measures the intra–region uniformity to get the performance of segmentation. Examples of Inter-region metrics are Color error, Texture, Squared color error and Entropy. The Inter-region disparity metrics on other hand includes metrics based on region color difference, local color difference, metrics based on Bary Center distance and metrics based on layout entropy.

Metrics based on color error compares the difference between a pixels original color with the average color of its region based on some pre-specified threshold value in E_{CW} evaluation method. If the value is higher than the threshold, then it is termed misclassified pixels. Z_{eb} and D_{WR} classification methods also use metrics based on square error. The squared color error metric is the square of the color and is used by evaluation methods like F, F', Q, FRC. Metrics based on texture measures the uniformity of texture of a region and is used by evaluation methods like FRC and Busy. Metric based on entropy is used by evaluation methods like E and H_r.

Mean weighted distance was a metric used by Sapna et al. [1] for evaluating different segmentation techniques including clustering, thresholding, region-based and edge-detection. Normalized Probalistic Random index is the metric used by Unniskrishnan et.al in [12] to measure the performance of image segmentation techniques. Sughandi et al. in [14] suggested quantitative measures like discrete entropy, root mean square error and visible color difference for color image segmentation algorithms.

Table 2.2: Examples of Performance Metrics for Image Segmentation Techniques

Paper	Evaluation Metrics used
[10]	Color error Texture Squared color error Region color difference Local color difference Entropy
[1]	Mean weighted distance
[15]	PETs Metrics (Young DP) including *Overall regions (OR) Merged regions (MR), Accuracy ACC [4])* *Negative rate metric (NRM).*
[10]	Fuzzy metric B. McGuiness Evaluation Measure, A. Unnikrishnan Probabilistic Rand Index

Finally, Jaime et al. [15] proposed a metric that can be used for all applications that will give correct result provided that reference segmentation is available. The method can estimate the quality of segmentation the same a human observer can do. Though it is a step forward, the required reference segmentation makes dependent on human intervention. An ideal one would have been one without requiring a ground truth.

Table 2: Examples of Performance Metrics for Image Segmentation Techniques

S/N	Metrics	Type	Metric Strength	Metrics Weakness
1	Color error	Intra-region uniformity measure	Ideal for D_{WR}, E_{CW} and Zeb evaluation methods	Too sensitive to noise.
2	Squared color error	Intra-region uniformity measure	Ideal for F_{RC}, η, PV, NU, F, F`, Q evaluation methods	Not ideal for noisy/textured images
3	Texture	Intra-region uniformity measure	Ideal for Busy, PV, V_{CP}, F_{RC} evaluation methods	Causes under segmentation
4	Region color difference	Inter-region disparity measure	Ideal for η, PV, F_{RC}, evaluation methods	Assume a single underlying distribution(eg Gaussian distribution)
5	Local color difference	Inter-region disparity measure	Ideal for V_{CP}, Zeb, V_{EST} evaluation methods	Do not complement the inter-region uniformity measures.
6	Layout Entropy	Inter-region disparity measure	Ideal for SE, E evaluation methods	Rely on low- level feature extraction and not semantic meaning of segments
7	Barycenter distance	Inter-region disparity measure	Ideal for F_{RC} evaluation methods	Assume a single underlying distribution(eg Gaussian distribution)
8	Shape	Shape measure	Ideal for SM, V_{CP} evaluation methods	Highly dependent on application and type of images

4. CONCLUSION

Reviews of different technique of image segmentation from literatures have been presented in this work. Additionally image segmentation evaluation techniques and the underlying metrics used by these metrics are discussed. The metrics are listed; the evaluation methods that used them are also listed. The type, strength and weaknesses of each metric are outlined. It is concluded that the evaluation methods are highly dependent on the underlying performance metrics and consequently affects the evaluation results given by such techniques. Problems like noise, under segmentation, use of low-level features for evaluation and assumption of single underlying distribution and all concerned with the underlying metric used by that evaluation technique .Future work include trying to solve the shortcomings of these metrics and consequently the short coming of the evaluation methods that uses them.

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