A Grayscale Segmentation Approach Using the Firefly Algorithm and the Gaussian Mixture Model

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ABSTRACT

In this article, the author proposes an unsupervised grayscale image segmentation method based on a combination of the Firefly Algorithm and the Gaussian Mixture Model. Firstly, the Firefly Algorithm has been applied in a histogram-based research of cluster centroids. The Firefly Algorithm is a stochastic global optimization technique, centred on the flashing characteristics of fireflies. In this histogram-based segmentation approach, it is employed to determine the number of clusters and to select the gray levels for grouping pixels into homogeneous regions. Successively these gray values are used in the initialization step for the parameter estimation of a Gaussian Mixture Model. The parametric probability density function of a Gaussian Mixture Model is represented as a weighted sum of Gaussian components, whose parameters are evaluated applying the iterative Expectation-Maximization technique. The coefficients of the linear super-position of Gaussians can be thought as prior probabilities of each component. Applying the Bayes rule, the posterior probabilities of the grayscale intensities have been evaluated, therefore their maxima are used to assign each pixel to the clusters, according to their gray levels.

KEYWORDS

Clustering Images, Firefly Algorithm, Gaussian Mixture Model, Image Segmentation, Metaheuristic Algorithm

1. INTRODUCTION

Image segmentation is the decomposition of an image into meaningful structures, it is often an essential step in image analysis, object representation, visualization, and many other image processing issues and it is aimed at facilitating the tasks at higher levels, such as object detection and recognition.

The basic goal of any image segmentation process is to subdivide an image into components belonging to different objects or to different parts of an object. Theoretically, pixels derived by the same component should have similar intensities, forming a connected region (Russ & Neal, 2015). Image segmentation is a preliminary step in image processing, playing a role of great relevance in object recognition and classification, machine learning, image learning and understanding. Gonzalez R.C. & Wood, 2007). During the last decades many segmentation methods have been proposed in literature and for an in-deph overview of clustering techniques refer to (Nikhil & Sankar, 1993), (Jain, Murry & Flynn, 1999), (Herbert & Pantofaru, 2005), (Zaitoun & Musbah, 2015).

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The threshold-based segmentation approach is one of the simplest and widely-used in computer vision. In thresholding methods, pixels are partitioned depending on their intensity levels, recurring to a global thresholding, with a single threshold \(T\), or to a variable thresholding if \(T\) changes over the image, or to multiple thresholding values \(T_1, \ldots, T_n\). Global thresholding maps a gray-valued image into a binary image, hence it can be suitable to segment an image into objects and background. Threshold segmentation can be extended to use multiple thresholds to decompose an image into more than two segments. Many methods exist to select threshold values for a segmentation task, among them we could mention the image histogram-based approaches, which are often valuable tools in establishing suitable thresholding values (Ridler & Calvard, 1978), (Chen & Chen, 2009).

In edge-based segmentation, an edge operator is applied to the image for detecting meaningful discontinuities in intensity values. The ascertained edges are assumed to be object or region boundaries, therefore pixels are classified in such a way that those which are not separated by an edge are assigned to the same region or category (Bresson, Esedoglu, Vandergheynst, Thiran & Osher, 2007), (Mahmoud & Marshall, 2008).

Region-based segmentation algorithms operate iteratively by grouping together pixels which have neighbours with similar values and splitting groups of pixels which are dissimilar.

More specifically, edge-based techniques attempt to find object boundaries and then to allocate pixels by filling them in, whereas region-based techniques apply an opposite approach, by starting in a specific position of a region from which pixels are adjoined outward until boundaries are met (Gould, Fulton & Koller, 2009), (Gu, Lim, Arbelaez & Malik, 2009).

Another category of clustering methods performs an image partition trying to minimize the intra-cluster differences and maximize the inter-cluster differences. These approaches are usually classified into two types; hierarchical clustering and partitional clustering. Hierarchical clustering produces a nested series of partitions based on a criterion for splitting or merging clusters. On the contrast, partitional clustering segmentation is carried out by partitioning the data into a fixed number of clusters, using similarity measures. A commonly used partitional clustering method is the K-means algorithm (Frigui & Krishnapuram, 1999), (Senthilnath, Omkar & Mani, 2011), (Senthilnath, Vipul Das, Omkar & Mani, 2012). Traditional K-means clustering algorithms have the drawback of being strongly affected by predefinition of the number of clusters and the initial values of centroids, thus the results will generally depend on the initialization parameters.

In this work we propose a method for grayscale image segmentation obtained through a histogram-based segmentation approach which recurs to a nature-inspired algorithm for defining automatically the number of clusters and the histogram maxima.

Traditional optimization algorithms have the disadvantage of being stuck on local maxima. Therefore, in this work we suggest the application of nature-inspired optimization algorithms because they guarantee an enhancement of convergence into global optima due to the simultaneous action of multiple agents moving randomly all around the research space.

Subsequently, the detected maxima are used as initial means for the parameter estimation of a Gaussian Mixture Model. The probability density function of a Gaussian Mixture Model is expressed as a weighted sum of Gaussian density functions, whose parameters are evaluated applying the Expectation-Maximization (EM) technique. The coefficients of the linear combination of Gaussians can be seen as prior probabilities of each component while the posterior probabilities, derived by the Bayes rule, can be used for assigning pixels to clusters without recurring to a thresholding process.

2. METHODOLOGY

Over the last few decades, researchers started to use metaheuristic algorithms for clustering to overcome the limitations of the existing conventional clustering algorithms that are generally deterministic, (Osman & Laporte, 1996). Metaheuristic algorithms are a class of approximate methods that allow
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