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A novel image segmentation method based on fast density clustering algorithm

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ABSTRACT

Image segmentation is one of the key technologies for image processing. Most image segmentation methods based on clustering algorithms encountered with challenges including cluster center sensitivity, parameter dependence, low self-adaptability and cluster center determination difficulty. Accordingly, a novel image segmentation method based on fast density clustering algorithm (IS-FDC) is proposed in this paper. Pixel similarity is calculated on basis of both pixel value and its position information. IS-FDC is based on fast density clustering algorithm (FDC), in which cluster centers could be determined automatically by multiple linear regression analysis, and the only sensible parameter confidence interval is self-adaptive based on cuckoo search algorithm (CS). Currently density based clustering algorithms applied to image segmentation have difficulties, especially for its high time complexity and memory complexity. Parallel partition and scaling strategies are put forward to speed up clustering process. Multiple images from Berkeley dataset are adopted for simulations and analysis. IS-FDC is compared with several outstanding algorithms based on several evaluation indexes including both supervised and unsupervised algorithm indexes to testify that the proposed IS-FDC is outperformed. Abundant experimental results proved that IS-FDC is robust to parameters, which can automatically determine the number of segmentation and improve the accuracy of segmentation effectively.

1. Introduction

As the basis of computer vision and image processing application, image segmentation is used to divide image into several regions of specific and unique properties. Pixels in the same region are of stronger similarities, while pixels from different regions are of stronger differences. Meanwhile, image segmentation is an important step for further image understanding. Currently lots of image segmentation methods are designed and applied including edge detection based segmentation, region based segmentation and specific theory based segmentation. After image segmentation completed, objects extracted from segmentation result can be further used for image semantic recognition, image search or other applications. So the accuracy of image recognition or search will be directly affected by image segmentation quality (Zaitoun and Aqel, 2015).

In edge detection based segmentation, segmentation boundary is usually detected through high gray gradient locations (Canny, 1986). Differential operator is used to detect edge, including first order differential operator and the second order differential operator (Xiang et al., 2006). Region based segmentation includes parallel region segmentation and its serial. Threshold segmentation method is the most typical parallel region segmentation technique, which has high segmentation efficiency and processing speed. Otsu can obtain better segmentation result by adopting adaptive threshold (Ning-ning, 2011). Region growing and split-merging are typical serial regional techniques. The segmentation results are directly influenced by growth criterion and split-merging criterion (Ma and Han, 2006). However the performance of region growing method mainly depends on initial seeds selection and growth order (Vieira et al., 2016). It is found that in region splitting, the boundary will be broken because of blocking artifact (Zoghoul et al., 2016).

With the new theories of different disciplines proposed, there are many image segmentation methods which are combined with specific theories and methods such as genetic algorithm, artificial neural network and clustering analysis (Saha et al., 2016). As a popular research topic, a series of elegant image segmentation methods based on clustering algorithm are proposed (Alok et al., 2016), including Fuzzy C-means, K-means, Ncut, SLIC, Mean-shift and etc.

Fuzzy C-means is a fuzzy clustering algorithm based on objective function by introducing the fuzzy concept into image segmentation problems so that an object could be clustered into several classes at

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the same time (Kang et al., 2005). WHIFCM algorithm was proposed for colored image based on improved FCM clustering algorithm (Rajaby et al., 2016). Better performances could be obtained by introducing color and brightness information clustering process. However, the initial cluster centers need to be specified in prior (Ji et al., 2012). Image segmentation method based on K-means algorithm is easy to implement and suitable for large image database because of its scalability and high efficiency. However, parameter K-value needs to be set in prior. The segmentation result will be affected by initial cluster centers, which is easily to converge to the local optimal (Moftah et al., 2014). Ncut (Normalized cut) algorithm is based on spectral graph theory, which grasps main information by dimension reduction and it is robust to irregular data. Ncut algorithm has faster clustering speed and better segmentation result by K-means based on feature vectors compared with other methods (Helmy and El-Taweel, 2016). Similarity threshold needs to be preset, and K-value should be set in Ncut. SLIC (simple linear iterative clustering) is a simple linear iterative clustering algorithm, which is used to generate super pixels. In SLIC, segmentation results will be greatly affected by K-value, and edge points and noise points would be more like to be considered as initial seeds (Wang et al., 2016). Further consolidated operation is necessary after SLIC. Mean-shift is also an iterative algorithm (Zhou et al., 2013). The step size is adaptive, which can effectively shorten search time and accelerate convergence rate to reach global optimum. However several disadvantages limit its further applications, including high time complexity, and many parameters need to be preset, including initial cluster centers, search radius of color space and coordinate space, value of pyramid layer, etc. And small regions need to be merged after segmentation (Zhou et al., 2014).

The rest of paper is organized as follows. In Section 2, we discuss related works of novel clustering algorithms and its applications to image segmentation. Section 3 introduces the proposed algorithm and its key technologies. Experiment results and analysis are shown in Section 4. Finally, Section 5 summarizes the main contribution of our work. Besides, more supplementary experimental results are list as Appendix.

2. Related works

Lots of clustering-based image segmentation methods haven been proposed and developed. Compared with other segmentation methods based on specific theories, clustering-based segmentation method provides a different idea for image segmentation. Meanwhile, recent research show that comprehensive utilization of color information of pixel, distance information between pixels, texture information of local region and context information of pixels can greatly promote segmentation result (Chen et al., 2013; Zhao et al., 2015). And the key step of transforming image segmentation into clustering is that pixels in image space are represented as the corresponding points in feature space (Jia et al., 2014). However, hierarchical-based and partition-based clustering algorithm can only find convex clusters. Aiming at this problem, DBSCAN (Density-Based Spatial Clustering of Applications with Noise) algorithm defines cluster as a maximum set of point with high density. DBSCAN is robust to noise and adaptive to arbitrary shape clusters with noises. Each cluster in DBSCAN is composed of a group of dense data points, which is separated by low density regions in data space. The purpose is to find dense data points by filtering low density region. And then the remaining points are classified according to the number of data points in cluster is not less than given threshold. Compared with traditional clustering algorithms, DBSCAN is robust to cluster shape, and has high flexibility such as parameter selection for filtering noise. However, DBSCAN cannot directly applied to processes the entire large dataset because of high memory consumption and high time complexity.

A novel characterization method for cluster centers based on fast search of density peaks was proposed (Rodriguez and Laio, 2014), which was designed based on the idea that cluster centers are characterized by a higher density than their neighbors and by a relatively large distance from points with higher densities. Satisfying performances are shown in clustering according to the experimental result of irregular dataset, which can weaken the influence of noise points. According to different similarity calculation mechanism, the algorithm could be easily influenced by three elements including region size of density calculation, range of cluster centers in decision graph and algorithm stability. The final evaluation of clustering result could be given in a more specific way, in other word, it could be applied to image segmentation effectively. A universal distance calculation method (Chen and He, 2015) was proposed for different data types by analyzing the characteristics of mixed data. Cluster centers can be automatically determined by linear regression models and residual analysis according to decision graph. And the only sensitive parameter optimal density range is determined by the particle swarm optimization algorithm. The algorithm shows good performance in both aspects of clustering accuracy and average purity in application of mixed data processing according to clustering analysis of several classical datasets. And final clustering results accord with the distribution of original data. The only problem is that dominant factor needs to be tested by dataset, and algorithm complexity is relatively higher than typical algorithms.

Density-based clustering algorithm is applied to image segmentation in paper (Chen et al., 2015), where the number of clusters and the location of cluster centers are automatically determined by decision graph. And region size of density calculation in experiments is determined by fixed percentage of global area. Compared with classical algorithms, the number of segmentation and the location of cluster centers can be selected according to demand. However, cluster centers cannot be automatically identified in the process of segmentation, and there is no specific indices judge the quality of segmentation results. A novel label inference approach for segmenting natural images into perceptually meaningful regions was adopted (Dong et al., 2016). The original image is over-segmented according to the clustering algorithm based on density peaks firstly. Then final recognition result is obtained by merging homogeneous regions based on cross-region potential and cross-scale potential. The pixel value and position information are considered in the process of segmentation. And the segmentation covering (SC) and the Rand Index (RI) were used as quantitative evaluation indicators of segmentation result. The deficiencies of this method are that high algorithm complexity, slow image processing speed, and cluster centers determined manually.

Although most current clustering-based segmentation methods have solved the image segmentation problem to some extent, they are not able to segment the image without setting the clustering number prior. In addition, algorithm performances are sensitive to the initial selection of cluster centers. Inspired by density clustering algorithm (Chen and He, 2015), we propose a novel image segmentation method based on fast density clustering (IS-FDC). The main contributions of our work could be concluded as follows.

(1) To our best knowledge, fast density based clustering algorithm with cluster center automatic determination is applied to image segmentation for the first time. And we achieve excellent simulation and practical results of our algorithm.

(2) Multiple linear regression analysis is applied to automatically determine cluster centers to overcome initialization difficulty of cluster center.

(3) There is only one sensible parameter confidence interval in IS-FDC, and it is self-adaptive based on cuckoo search algorithm (CS). In other word, our IS-FDC is parameter independent which is capable of wider applications.

(4) In IS-FDC, parallel partition and scaling strategies are put forward to speed up clustering process. Simulation and practical results proved that our algorithm could reduce time complexity sharply. There is a remarkable margin between ours and the other algorithms.