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Improving feature space based image segmentation via density modification

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ABSTRACT

Feature space based approaches have been popularly used to perform low-level image analysis. In this paper, a density modification framework that enhances density map based discriminability of feature values in a feature space is proposed in order to aid feature space based segmentation in images. The framework embeds a position-dependent property associated with each sample in the feature space of an image into the corresponding density map and hence modifies it. The property association and embedding operations in the framework is implemented using a fuzzy set theory based system devised with cues from beam theory of solid mechanics and the appropriateness of this approach is established. Qualitative and quantitative experimental results of segmentation in images are given to demonstrate the effectiveness of the proposed density modification framework and the usefulness of feature space based segmentation via density modification.

1. Introduction

Image segmentation is a critical component of low-level image analysis. Image segmentation is a process of dividing an image into different regions such that each region is uniform in a certain sense and the union of any two regions is not uniform.

Feature space analysis based approaches have been popularly used to perform image segmentation. Initial works resulting in such segmentation techniques were based on finding thresholds in gray-level (single feature) histograms of images [12,30,33,43] and they are still widely used due to their simplicity. Segmentation based on values of multiple features at various pixels in an image are performed by first obtaining the thresholds in one dimensional histograms corresponding to the different features and then by employing the thresholds in the underlying multidimensional feature space [20]. Such a multiple feature based image segmentation method is a monothetic approach, where each feature is separately considered for analysis. Clustering techniques, which are polythetic (simultaneous consideration of multiple features) in nature, are also used in multidimensional feature space to carry out image segmentation. A broad review of clustering based image segmentation approaches is given in [11].

Many thresholding, clustering and other decision making systems used for feature space based segmentation consider judicious but speculative formulations of the underlying problem [35]. For example, many histogram thresholding techniques are based on prior assumptions such as the histogram fits a particular model very well or valleys in the histogram represent class boundaries. Partitional clustering techniques such as c-means and its variations [6,18,22] make assumptions about prototypes and shapes of the clusters to be formed, mode seeking algorithms [1,3,11] assume local modes (maxima) in the density of the samples in the feature space as cluster prototypes and mixture resolving algorithms [6,11] assume that the

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density of the samples in the feature space appropriately fits a particular model. Hierarchical clustering algorithms [6,11] assume a specific function to measure the similarity between clusters in the feature space. Assumptions such as the aforesaid ones corresponding to various decision making algorithms may or may not be appropriate for the feature space based low-level image analysis task at hand as they may or may not be in harmony with the representation of various contents (regions) of an image in a feature space. For example, it is very difficult to ascertain that clusters formed in an image feature space using the c-means algorithm, where cluster means are considered as cluster prototypes, would correspond to the natural regions in the underlying image.

Let us now consider the perspective that many systems that perform segmentation through feature space analysis actually categorize the feature values in an image feature space based on the density map of samples in the feature space. Therefore, although it is difficult to ascertain the appropriateness of a system for a feature space based segmentation task, one way of improving its performance could be by using some additional useful information such that density map based discriminability of feature values in the underlying feature space is enhanced. In this paper, we suggest that in order to enhance density map based discriminability of feature values in an image feature space, additional useful information could be suitably embedded into the density map of samples in the feature space resulting in its modification. Segmentation could then be carried out considering the feature space with the modified density map. Note that, by density map, we refer to the density of samples at various positions (values of features) in a feature space and density map based discriminability of feature values essentially means the discriminability of feature values based on the distribution of samples in the corresponding feature space.

A few other density modification techniques designed to aid segmentation are reported in [9,43]. In [43], histogram modification is considered in order to aid valley seeking based threshold determination in gray-level feature spaces for image segmentation. A histogram transformation technique is proposed in [9] to aid the application of Gaussian mixture resolving algorithm in gray-level feature spaces for bi-level segmentation.

Note that, the aforesaid density modification approaches do not belong to the class of techniques referred to as image pre-processing (enhancement, smoothing, noise reduction, redundant information removal) [8,26,40], which is widely used for favorably transforming an image before segmentation. The aforesaid density modification approaches do not transform the image in order to aid image segmentation. Hence, they are very much a part of the segmentation process itself and they are not image pre-processing algorithms.

Methods for improving performance of segmentation systems by other means have also been presented in literature. In [31], an adaptive approach has been presented to improve the effectiveness of the thresholding technique of [30]. In [2,21], edge strengths at image pixels have been used to aid threshold determination for segmentation. In [25], an approach to ensemble different thresholding algorithms has been considered to increase the efficacy of threshold determination. Use of kernel functions [36] to make clustering more effective in the presence of nonlinearly separable classes has been popularly used [5,18,47] for image segmentation. Clustering has been improved in [41,45] by considering robustness towards noise and outliers. In [14], performance of a class of clustering methods is improved by achieving certain relaxation in an inherent optimization approach and simplification of mixture models is considered in [46] to make clustering efficient in practical applications. In [15], a new measure of cluster quality is considered to improve clustering performance in the presence of arbitrarily shaped classes. In [27], the concept of shadowed sets is used to improve the performance of c-means clustering algorithm for segmentation by efficiently handling overlapping among segments while modeling uncertainty among the boundaries. Performance of image segmentation using artificial immune system based clustering is improved in [44] by considering the fusion of complementary features representing image texture. Performance of image segmentation by rough set theoretic thresholding is improved in [23] by considering adaptation to spatial data relationships. In [19], segmentation based on fuzzy clustering is improved by creating a provision to define a prior distribution and finding the segments using fuzzy minimax approach. In [17], region-based image segmentation has been considerably enhanced by designing an effective approach to deal with intensity inhomogeneities. A Bayesian network model based interactive segmentation technique is presented in [48], where interventions are actively sought from human. This is an improvement over standard interactive segmentation techniques that passively depend on human to provide the exact intervention.

In this paper, we propose a density modification framework, which enhances density map based discriminability of feature values in a feature space, to aid feature space based segmentation of images. In the proposed framework, first, fuzzy set theory is used to associate a position (feature value) – dependent property with each sample in a feature space of an image and then this property is embedded into the corresponding density map resulting in its modification. We propose the use of beam theory from the field of solid mechanics to carry out the property association and embedding processes in the framework. We also establish that the use of beam theory based property association and embedding processes indeed enhances density map based discriminability of feature values in the underlying feature space. Segmentation is performed considering feature spaces with modified density map obtained using the proposed density modification framework. The effectiveness of the proposed density modification framework is demonstrated by qualitatively and quantitatively comparing the segmentation performances achieved with and without the use of the proposed framework. In addition, the novel approach of feature space based segmentation via density modification is compared to two popular and state-of-the-art segmentation approaches, both qualitatively and quantitatively.

The organization of the paper is as follows. In Section 2, the novel framework for density modification in a feature space of an image is presented. The processes of beam theory based density modification in one dimensional and multidimensional feature spaces are presented in Sections 3 and 4, respectively, along with their justifications. Experimental results showing