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Cloud model-based method for range-constrained thresholding ☆

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ABSTRACT

Thresholding is a popular image segmentation method that converts a grayscale image into a binary image. In this paper, we propose a cloud model-based framework for range-constrained thresholding with uncertainty, and improve four traditional methods. The method involves four major steps, including representing the image using cloud model, estimating the automatic threshold for gray level ranges of object and background, implementing image transformation to focus on mid-region of the image, and determining the binary threshold within the constrained gray level range. Cloud model can effectively represent various visual properties of the image, such as intensity-based class uncertainty, intra-class homogeneity, and between-class contrast. The approach is validated both quantitatively and qualitatively. Compared with the traditional state-of-art algorithms on a variety of synthetic and real images, with or without noisy, as well as laser cladding images, the experimental results suggest that the presented method is efficient and effective.

1. Introduction

Thresholding is one of the simplest and most important methods for image segmentation, and has served a variety of applications, such as object recognition, image analysis and scene interpretation [1,2]. From a grayscale image, thresholding can be used to create a binary image, corresponding to the background and objects respectively. Over the years, a lot of image thresholding approaches have been proposed, and a number of performance evaluation metrics have been developed. Comprehensive overviews and comparative studies of image thresholding can be found in the literature [3], in which the Otsu method [4], the Kittler method [5] and the Kapur method [6] have been taken as the state-of-art algorithms, and misclassification error (ME) [7] is as the traditional evaluation metric.

The Otsu method [4] assumes that the image to be segmented contains two classes of pixels or bi-modal histogram (objects and background), then calculates the optimum threshold separating those classes so that their combined spread (intra-class variance) is minimized and the between-class variance is maximized. The Kittler method [5] views the histogram as an estimate of the probability density function of a Gaussian mixture population, that is, the pixels in the object and the

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background come from a normal distribution and the normal distributions may have different means as well as variances. Then the optimum threshold is selected so that the relative entropy-based mismatch between Gaussian mixture model and image histogram is minimized. Recently, Xue presented two median-based extensions on the conditions of skew or heavy-tailed class-conditional distributions [8], and then theoretically analyzed the close relationship between the Otsu method and the Kittler method, and stated that the Otsu method can be viewed as a special case of the Kittler method, in which equal sizes and equal variances are further assumed for the two classes [9]. The Kapur method [6] divides the histogram of the image into two probability distributions, one representing the objects and the other representing the background. Then the optimum threshold is selected so that the sum of the entropies of these probability distributions is maximized. In general, these three methods are widely used in many applications. Regarded as the historic standard, they are highly cited by scientific publications, and also typically compared by other new methods [10,11]. Furthermore, the Otsu method is implemented as the default approach to image thresholding in MATLAB, which is widely used in academic and research institutions as well as industrial enterprises, and the Kittler method is ranked as the best by a comprehensive survey [3].

Nonetheless, each method has its own advantages, disadvantages and applied situations. These four methods are based on histogram analysis, and depend too heavily on the precise histogram of the given image, but not consider the uncertainty contained in the histogram, and neglect properties of human visual perception. In fact, uncertainty is an inherent part of image thresholding in real world applications [11,12], and the automatic selection of optimum threshold with uncertainty is still a challenge. Therefore, we should further extend and discuss the traditional image thresholding approaches from the developmental point of view. We believe that, cloud model can handle such uncertainty in a better way, since it provides us with more design degrees of freedom, at least the second order uncertainty.

In recent years, range-constrained image thresholding has received some attentions. Hu et al. [13] first confined the intensity frequency range of the object in the histogram, and presented a supervised thresholding approach which only analyzes the histogram of a region of interest, where the proportion of the background varies in a range estimated through supervision. Based on the range-constrained approach, Hu et al. [14] produced the transition region with the help of supervision and calculating the threshold from the transition region, and then Li et al. [15] improved this transition region-based method by unsupervised estimation for gray level ranges of object and background. The key issue in the range-constrained methods lies in image transformation, and the image is divided into three portions via the upper and lower bounds for background and object. Li et al. [16] introduced image transformation [15] as a preprocessing step into local entropy-based transition region extraction and proposed a modified thresholding approach. These range-constrained methods have been proved to be useful in some cases. However, all of them have not considered the uncertainty contained in the histogram, and not completely investigated the effect of image transformation. For example, the Li method [15,16] determined the gray level ranges of object and background by T_u and T_l, which are related with the mean and the standard deviation of the image, and a parameter β automatically selected by statistical iterations according to the standard deviations of its three portions. Standard deviation is a common statistical measure reflecting degree of deviations between mean and individuals. That is to say, the Li method confined the intensity frequency range by intra-class similarities of the background and foreground, which considers only the intra-class homogeneity [17], but not the histogram contrast or the between-class contrast [10], much less class uncertainty [12].

In this context, we propose a cloud model-based framework for range-constrained thresholding with uncertainty, and improve four traditional methods under the new framework. In this paper, our first major contribution is a cloud model-based framework for image thresholding. Our intentions are two-folds: (1) using cloud model to provide a thresholding framework that can handle the uncertainties in a more robust way, and (2) providing an unsupervised approach (parameter-free) under the framework to study accounting for various visual properties of the image, such as intensity-based class uncertainty, intra-class homogeneity, and between-class contrast, which are reflected by the numerical characters of cloud model. Cloud model is a cognitive model between a qualitative concept and its quantitative instantiations [18,19], and has been used in image thresholding with uncertainty [20,21]. The cloud model-based thresholding consists of four steps, including representing the image using cloud model, estimating the automatic threshold for gray level ranges of object and background, implementing image transformation to focus on mid-region of the image, and determining the binary threshold within the constrained gray level range. Under the framework, the performance of image transformation is compared with Li's method [15,16] in the first group experiment.

As the second major contribution, we improve four traditional image thresholding approaches under the cloud model-based range-constrained framework, and the selected approaches are based on grayscale-level threshold optimization using histogram statistics, not pixel-level or others, including the Otsu method, the Kittler method, the Kapur method and the median-based extension for the Otsu method (hereafter referred to as the Xue method). The improved methods process the transformed images by applying the criteria of conventional approaches and search the optimal threshold in a more efficient and effective grayscale range. We have done quantitative and qualitative validation of the proposed approach against several images, with or without noise, as well as laser cladding images. Comparison has been made with respect to the Otsu method [4], the Kittler method [5], the Kapur method [6], and the Xue method [8]. The results demonstrate that our approach is efficient and effective. Theoretically, the efficiency comes from the reducing of the grayscale range for the optimizing search, and the effectiveness roots in the strong relevance between the optimal threshold and the grayscale range, inspired by human vision.

The rest of the paper is organized as following: Section 2 provides an introductory explanation of cloud model, and universal principles of human visual perception. Then, Section 3 proposes a cloud model-based framework for threshold