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Fuzzy entropy based optimal thresholding using bat algorithm

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ABSTRACT

Image segmentation is a very significant process in image analysis. Much effort based on thresholding has been made on this field as it is simple and intuitive, commonly used thresholding approaches are to optimize a criterion such as between-class variance or entropy for seeking appropriate threshold values. However, a mass of computational cost is needed and efficiency is broken down as an exhaustive search is utilized for finding the optimal thresholds, which results in application of evolutionary algorithm and swarm intelligence to obtain the optimal thresholds. This paper considers image thresholding as a constrained optimization problem and optimal thresholds for 1-level or multi-level thresholding in an image are acquired by maximizing the fuzzy entropy via a newly proposed bat algorithm. The optimal thresholding is achieved through the convergence of bat algorithm. The proposed method has been tested on some natural and infrared images. The results are compared with the fuzzy entropy based methods that are optimized by artificial bee colony algorithm (ABC), genetic algorithm (GA), particle swarm optimization (PSO) and ant colony optimization (ACO); moreover, they are also compared with thresholding methods based on criteria of between-class variance and Kapur's entropy optimized by bat algorithm. It is demonstrated that the proposed method is robust, adaptive, encouraging on the score of CPU time and exhibits the better performance than other methods involved in the paper in terms of objective function values.

1. Introduction

Image segmentation is an advancing research field in computer vision, the result of which is a set of segments that collectively cover the entire image, or a set of contours extracted from the image. Each of the pixels in a region is similar with respect to some characteristic or computed property, such as color, intensity, or texture. The goal of segmentation is to simplify or change the representation of an image into something that is more meaningful and easier to analyze. Over the years much work has been made in this field. For instance, [1] presented an automatic seeded region growing algorithm and merged similar or small regions for color image segmentation. [2,3] respectively used Sobel and Roberts operators, and then grouped edge pixels into contours or surfaces part that represented the boundaries part of the image. All of the above methods could complete the task of image segmentation. However, it is not stable and robust; in addition, it is difficult to obtain the optimal segmentation results. [4] designed an adaptive segmentation system for color document image analysis, which was based on the serialization of k-means algorithm that was applied sequentially by using a sliding window over the image. But it was sensitive to the isolated noise points and usually plunged into local minimum. [5] proposed a weighted image patch-based FCM (WIPFCM) algorithm for image segmentation, which incorporated local spatial information embedded in the image into the segmentation process. However, the required storage space of this method may significantly increase, which will cause a huge amount of computation and low operating efficiency for the whole algorithm. [6] presented a new method for color image segmentation, which divided the image into homogeneous areas by local thresholds. In general, the currently used image segmentation method may be summarized as four main categories: region-based method, boundary-based method, clustering-based method, and thresholding-based method. Owing to its intuitive properties and simplicity of implementation, thresholding method holds a primary position in the field of image segmentation [7,8].

A lot of endeavour has been done on the topic of image thresholding and many thresholding methods have been put forward. For example, [9] provided the classical thresholding method on the criterion of between-class variance for image segmentation. [10] presented a general technique for thresholding of digital images based on Renyi's entropy. [11] utilized particle swarm optimization (PSO) and artificial bee colony (ABC) combined with Kapur's entropy and between-class variance to find the optimal

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multi-level thresholds. [12] adopted a novel thresholding technique via proposing an energy function to generate the energy curve of an image and taking into an account the spatial contextual information of the image. Because of the fuzziness of real life image, recently image segmentation methods based on fuzzy theory have attracted much attention which could obtain satisfactory segmentation results. [13] gave a definition of the concept 'intuitionistic fuzzy set' (IFS), the latter being a generalization of the concept 'fuzzy set' and an example was described. [14] introduced a new nonprobabilistic entropy measure in the context of fuzzy sets or messages. [15] recalled the definitions of intuitionistic fuzzy sets and interval-valued fuzzy sets with the relation between these sets established by [13], which defined the distance measure between intuitionistic fuzzy sets and gave an axiom definition of intuitionistic fuzzy entropy on this basis.

Fuzzy sets play a significant role in many deployed systems by virtue of their capability to model nonstatistical imprecision [16]. Fuzzy entropy is a function on fuzzy sets that becomes smaller when the sharpness of its argument fuzzy set is improved. The notion of entropy, in the theory of fuzzy sets, was first introduced by [17]. There have been numerous applications of fuzzy entropies in image segmentation. Such as [18] proposed fuzzy homogeneity vectors to handle the grayness and spatial uncertainties among pixels, and to perform multilevel thresholding. [19] presented a thresholding approach by performing fuzzy partition on a two-dimensional histogram based on the fuzzy relation and the maximum fuzzy entropy principle. [20] considered the fuzzy memberships as an indication of how strongly a gray value belonged to the background or to the foreground. The optimum threshold was found as the threshold that minimized the sum of the fuzzy entropies.

[21] presented an entropy function by the fuzzy c-partition (FP) and the probability partition (PP) which was used to measure the compatibility between the PP and the FP. By adopting a simple monotonic function to approximate the memberships of the bright, the dark and the medium, it derived a necessary condition for the entropy function to be maximized, $p_d = p_m = p_b = 1/3$, and deduced an algorithm for three-level thresholding. The image is partitioned into three parts, namely the dark, dust and bright. However, the whole process needs a great deal of computation and efficiency is reduced. Therefore, in recent years, some modified methods using evolutionary algorithm and swarm intelligence optimization algorithms blending of fuzzy entropy have been put forward to further improve efficiency of fuzzy entropy based image thresholding.

Evolutionary algorithm and swarm intelligence are two similar subfields of artificial intelligence that involve continuous optimization and combinatorial optimization problems, which have been previously employed to perform entropy-based image segmentation. [22] proposed a new multi-level maximum entropy thresholding (MET) approach based on artificial bee colony (ABC) algorithm. [23,24] implemented genetic algorithm (GA) to find the optimal combination of the fuzzy parameters for fuzzy entropy based image segmentation. [25] introduced particle swarm optimization (PSO) into fuzzy entropy to meet the needs of the segmentation application. [26] investigated the performance of the fuzzy entropy approach application to the segmentation and ant colony optimization (ACO) was used to obtain the optimal parameters. Bat algorithm (BA) is a newly proposed stochastic global search algorithm, which has excellent performance on handing with optimization problem. [27] has made a conceptual comparison of BA, PSO and GA. The final results indicate that BA could converge to the optimal solution stably. Nowadays, BA has been widely used in diverse applications, e.g. [28] utilized BA to solve the brushless DC wheel motor problems. [29] intended to explore capabilities and potentials of BA in the realm of structural optimization. [30] used BA for discrete size optimization of steel frames. In the field of image processing, [31] have employed BA for image matching. [32,33] have tried to employ BA for image thresholding based on Kapur's entropy and realized fair good segmentation results. Further, there are some variants and modifications of BA, such as [34] proposed a binary BA and used it for optical buffer design. Douglas [35] applied a binary BA for feature selection. [36] proposed a self-adaptive BA that borrowed the self-adapting mechanism from self-adapted differential evolution, which performed better than the standard BA. However, the standard BA is by far the most popularly used. Hence, in this paper, a novel image segmentation technique is proposed using fuzzy entropy and blending of standard BA.

The rest of the paper is organized as follows: Section 2 makes a general description for the theory of maximum fuzzy entropy based image thresholding. Section 3 describes the basic theory of bat algorithm (BA) in brief. Section 4 presents the fundamental viewpoint of BA-based fuzzy entropy method. In Section 5, simulation results and discussion are displayed. Finally, conclusions will be drawn in Section 6.

2. Maximum fuzzy entropy theory based image thresholding

Let $D = \{(i, j) : i = 0, 1, \ldots, M-1 ; j = 0, 1, \ldots, N-1\}$ and $G = \{0, 1, \ldots, L-1\}$, where M, N and L are three positive integers standing for width, height and maximum gray-scale of an image. Let $I(x, y)$ be the gray level value of the image at the pixel (x, y) and $D_k = \{(x, y) : I(x, y) = k, (x, y) = D\}$, $k = 0, 1, \ldots, L-1$. Supposed that t_1 and t_2 are used as the thresholds, which divide the domain D of the original image into 3 parts, E_d, E_m and E_b. E_d is composed of pixels with low gray levels, E_m consists of pixels with middle gray levels, and E_b is made up of pixels with high gray levels. $\Pi_3 = \{E_d, E_m, E_b\}$ is an unknown probabilistic partition of D, its probability distribution can be expressed as [21]

$$p_d = P(E_d) \quad p_m = P(E_m) \quad p_b = P(E_b) \tag{1}$$

The membership functions is utilized (see Fig. 1) to approximate the memberships of the dark μ_d, the dust μ_m and the bright μ_b of an image with 2^8 gray levels. There are 6 parameters a_1, b_1, c_1, a_2, b_2, c_2 in membership function. That is to say, the thresholds t_1 and t_2 are dependent on the parameters of the membership functions [26]. For each $k = 0,1,\ldots,255$, let

$$\begin{aligned} D_d &= \{(x, y) : I(x, y) \le t_1, (x, y) \in D_k\} \\ D_m &= \{(x, y) : t_1 < I(x, y) \le t_2, (x, y) \in D_k\} \\ D_b &= \{(x, y) : I(x, y) > t_2, (x, y) \in D_k\} \end{aligned} \tag{2}$$

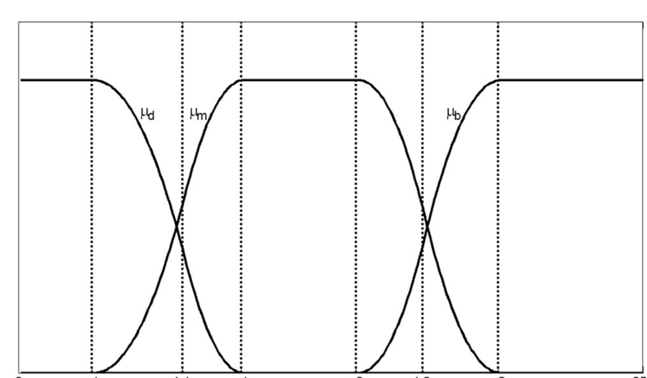

Fig. 1. Membership function graph (Tao et al., 2007).