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A new technique for multilevel color image thresholding based on modified fuzzy entropy and Lévy flight firefly algorithm☆

S. Pare[a], A.K. Bhandari[b,*], A. Kumar[a,1], G.K. Singh[c]

[a] PDPM Indian Institute of Information Technology Design and Manufacturing, Jabalpur, Madhya Pradesh 482005, India
[b] National Institute of Technology Patna, Bihar 800005, India
[c] Indian Institute of Technology Roorkee, Uttarakhand 247667, India

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ABSTRACT

In this paper, a modified fuzzy entropy (MFE) function is proposed to perform the multilevel thresholding of color images at different segmentation levels using Lévy flight guided firefly algorithm (LFA). Modified fuzzy entropy function is the difference of adjacent entropies. Therefore, minimizing the fitness function will provide thresholding levels such that all the regions have almost equal entropies. LFA algorithm improves the search performance and gains optimal threshold values for an efficient segmentation of colored images and satellite images. A comparative study of different nature inspired algorithms using MFE as an objective function presented. The study proves that the proposed MFE-LFA algorithm exhibits better performance in terms of different fidelity parameters and computation time. In addition, the proposed method is also compared with the most widely used Kapur's entropy based segmentation approaches, where the simulation results show the proposed methodology as the most efficient and effective algorithm.

1. Introduction

Color image segmentation plays an essential role in computer vision, which divides an image into a number of disjoint and homogeneous sub-regions based on abrupt changes in texture, color or gray-level values (histogram). Owing to the robustness and simplicity, thresholding technique has emerged as the most popular tool amongst various segmentation techniques developed in the literature [1]. Thresholding deals with segmenting an image into two or more classes depending on the segmentation application. Recently, as an alternative to exhaustive search processes of non-parametric approaches [2,3], there has been a growing interest towards the application of derivative-free metaheuristic optimizers in the framework of color multilevel thresholding. These techniques has been significantly adopted to enhance computational speed, and optimally search the threshold values for effective segmentation. Many researchers have formulated the non-parametric entropy functions as a fitness function for optimization algorithms to perform multilevel thresholding for segmentation [4–6]. Multilevel thresholding of satellite images or remote sensing images has emerged as an interesting area among researchers in

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* Corresponding author.
E-mail addresses: shreya.pare9@gmail.com (S. Pare), bhandari.iiitj@gmail.com (A.K. Bhandari), anilkdee@gmail.com (A. Kumar), gksngfee@gmail.com (G.K. Singh).
[1] Presently, visiting researcher, School of Electrical Engineering and Computer Science, Gwangju Institute of Science and Technology, Korea.

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past few years [7–12]. Satellite images contain information over a large range of scales; hence, they possess dense regions such as open spaces, water bodies, vegetation, concrete structures and various territory regions, which are not precisely separated due to poor spatial resolution and poor illumination [8]. In case of satellite or remote sensing image study, it is very fundamental to recognize the abrupt changes in information over various scales of imagery. Recently, Pare et al. [13] proposed a new multilevel color image thresholding method based on energy curve. In this paper, different objective functions such as Kapur's entropy, between-class variance, and Tsalli's entropy using Lévy flight based cuckoo search (CS) and egg laying radius based CS algorithm has been used to search optimum threshold values on energy curve. The results show that Kapur's entropy Lévy-CS provides accurate and efficient multi-threshold color image segmentation. In 2017, authors in [14] proposed GLCM and CS algorithm based multilevel thresholding of satellite images. However, it has been noticed that the accuracy of the method is not very satisfactory due to the inherent fuzziness and uncertainties in the satellite images.

Besides the complex characteristics, images are also ambiguous in nature, thus to deal with the uncertainty and fuzziness in image processing, fuzzy entropy has been introduced in multilevel thresholding to gain better results [15]. Zhao et al. proposed the fuzzy entropy for measuring the compatibility of fuzzy c-partition and probability partition by adopting membership function of bright, gray, and dark areas [16]. Furthermore, Tao et al. [17] improved this fuzzy entropy principle and used Z-function, Π-function and S-function as membership functions of the three levels. Then, GA has been implemented to maximize the fuzzy entropy for fast 3-level thresholding. Afterward, Lan et al. [18] incorporated the new fuzzy entropy using two-dimensional (2-D) histogram and GA to perform 3-level thresholding. Later, this fuzzy entropy has been maximized using Bat algorithm to perform gray-scale multilevel thresholding upto 5-segmentation levels [19]. The above techniques have been limited to perform multilevel thresholding based segmentation of monochrome images. Moreover, these techniques are inappropriate when N is too large in N-level thresholding.

Extracting the target information accurately through segmentation of high-resolution remote sensing images that exhibit numerous regions, low resolution, and poor illumination is an onerous task [8]. On the other hand, unlike monochrome image segmentation, where no parameter or few parameters are tuned; the color image segmentation requires more parameters to be adjusted for achieving optimality. Thus, allocating different class levels with accuracy for all pixels is a significant issue and results are often objective to a certain degree [5].

In this paper, fuzzy entropy function [17,19] is modified to perform multi-threshold segmentation of color images and satellite images at various segmentation levels. The proposed modified fuzzy entropy (MFE) function is the sum of difference of all adjacent thresholded regions required. Therefore, minimizing MFE will provide thresholding levels such that all the regions have almost equal entropies. Hence, it has an ability to perform proficient and computationally fast segmentation of complex colored images at N segmentation levels. It is tedious to find optimal threshold values using exhaustive search procedure, therefore meta-heuristic algorithm is employed to achieve fast and accurate segmented results.

This paper focus on Firefly algorithm (FA) based multilevel thresholding. FA is a swarm-based meta-heuristic algorithm, modeled on the basis of light intensity variation and formulation of attractiveness by invertebrates such as glowworm and firefly [20]. Encouraged by the successful results obtained through Lévy flight based FA (LFA) [21,22], this paper incorporates LFA to gain optimal combination of fuzzy parameters by minimizing MFE, and hence determines the optimum threshold values for achieving accurate and computationally fast multilevel color thresholding.

The proposed (MFE-LFA) approach is a robust method that efficiently preserves the edge information by selecting optimum and precise threshold values; consequently, suitable to perform proficient color multilevel thresholding. To demonstrate the feasibility and superiority, the presented strategy is executed to partition 10 different color images including satellite images, and benchmarked with state-of-art meta-heuristics such as particle swarm optimization (PSO) [9,23], artificial bee colony (ABC) [8,23], adaptive differential evolution (JADE) [24], and CS [7,13]. Additionally, comparison with most popular Kapur's entropy based segmentation methods using afore-mentioned optimization algorithms is also presented. The quality of segmented results evaluated visually, and statistically states that the proposed segmentation strategy outperforms other participating algorithms while exhibiting accuracy, stability and faster computation at all the segmentation levels.

The remainder of this paper is organized as follows. Section 2 discusses the proposed MFE function. Section 3 outlines the LFA algorithm. Section 4 elaborates the proposed segmentation strategy resorted in this paper for multilevel thresholding. Section 5 illustrates the effectiveness of proposed methodology by simulation experiments. Finally, Section 6 briefs conclusion of the paper.

2. Problem statement

The color image multilevel thresholding is the process of determining two or more optimum thresholds for each of the three components (red, green, and blue) of the color image. In RGB image, each color component comprises N pixels and L number of grey-levels, and the optimum thresholds are determined within the range [0 to $L-1$] to obtain the segmented image. Each of the gray-level is associated with the histogram $h(i)$ representing frequency of ith gray level pixel. Consider an original image I to be sub-divided into multiple regions. Assuming that there are $k-1$ thresholds, [T_1, T_2,.....,T_{k-1}] that segments I into set of k distinct classes: C_0 for {0,...,T_1}, C_2 for {T_1+1,...,T_2},...., C_k for{T_{k-1},...., $L-1$}. Consequently, a vector of optimal thresholds $\{T_1^*, T_2^*, ..., T_{k-1}^*\}$is determined using:

$$\{T_1^*, T_2^*, ..., T_{k-1}^*\} = \arg\max\{fit(T_1, T_2, ..., T_{k-1})\} \quad (1)$$

Subject to $0 \le T_0 < T_1 < ..... < T_{k-1} \le L-1$

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