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An efficient method for multilevel color image thresholding using cuckoo search algorithm based on minimum cross entropy

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ABSTRACT

Among various thresholding methods, minimum cross entropy is implemented for its effectiveness and simplicity. Although it is efficient and gives excellent result in case of bi-level thresholding, but its evaluation becomes computationally costly when extended to perform multilevel thresholding owing to the exhaustive search performed for the optimum threshold values. Therefore, in this paper, an efficient multilevel thresholding technique based on cuckoo search algorithm is adopted to render multilevel minimum cross entropy more practical and reduce the complexity. Experiments have been conducted over different color images including natural and satellite images exhibiting low resolution, complex backgrounds and poor illumination. The feasibility and efficiency of proposed approach is investigated through an extensive comparison with multilevel minimum cross entropy based methods that are optimized using artificial bee colony, bacterial foraging optimization, differential evolution, and wind driven optimization. In addition, the proposed approach is compared with thresholding techniques depending on between-class variance (Otsu) method and Tsalli's entropy function. Experimental results based on qualitative results and different fidelity parameters depicts that the proposed approach selects optimum threshold values more efficiently and accurately as compared to other compared techniques and produces high quality of the segmented images.

1. Introduction

Computer-based color image segmentation contributes a fundamental step, which deals with segmenting a digital image into a set of non-intersecting and contiguous homogenous regions (or segments) on the basis of discontinuity or abrupt changes in texture, edges, color or gray-level values (histogram). The prominent objective of the color image segmentation is to localize boundaries and objects within images, remote sensing information classification and retrieval. Owing to the advancements in remote sensing instruments, satellite images have gained huge importance in several applications such as astronomy, geographical information system, and geo-science studies. Complexity increases in case of images containing multiple objects or segmentation categories, thus extracting target information present in the high resolution remote sensing images or color images becomes a challenging problem.

A number of image segmentation techniques have been devised in last few decades [1–4]. Among all the existing techniques, the thresholding based approaches are more robust, simple and accurate [5,6]. Due to the advancements in information theory, entropy based image thresholding techniques have attracted considerable attention as they perform much better image segmentation [7]. Initially, these techniques were introduced for bi-level, and then later developed for multilevel thresholding of monochrome images [8–13]. However, it has been notices that the multilevel thresholding of images using classical implementations leads to significant difficulties as they are associated with high computational cost and inefficient exhaustive search for best threshold values.

To overcome such limitations, researchers formulated the existing entropy criterion as an objective function, and incorporated nature-inspired optimization algorithms to improve the computational speed of multilevel thresholding. A comparative study of different meta-heuristic algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO),

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Tabu search, simulated annealing (SA), and differential evolution (DE) to solve Otsu's multilevel problems has been provided in [5]. A parallel genetic SA to reduce complexity of 2-D entropy method has been introduced in [14]. Different quantum inspired meta-heuristic algorithms aided multilevel thresholding has been formulated in [15–17]. Derivative-free metaheuristic optimizers have so far been applied successfully to perform entropy based image multilevel thresholding of gray-scale images [14–19].

In last few years, multilevel thresholding methods for monochrome images have been extended for color images by using red (R), green (G) and blue (B) frames or their transformations. Various meta-heuristic optimization algorithms along with their variants have been adopted to solve the problem of multilevel thresholding for color images. A comparative study shows that swarm-based algorithms such as PSO, artificial bee colony algorithm (ABC), cuckoo search (CS), and differential search algorithm are more efficient for multilevel color image segmentation as compared to evolutionary algorithms like evolution strategy, GA, DE, adaptive DE [20]. An effective multilevel thresholding algorithm based on minimum cross entropy (MCE) using DE [21], and quantum inspired ACO technique [16], has also been proposed in this direction. Moreover, in favor of multilevel satellite image segmentation, Ghamisi et al. [22] proposed Otsu's function aided with fractional-order Darwinian PSO based gray-scale multilevel thresholding approach. Bhandari et al. proposed various techniques based on different entropy functions to solve multilevel thresholding problems for gray-scale satellite images based on CS, wind driven optimization (WDO) [23], and modified ABC [24]. Pare et al. [25] proposed a GA based multilevel thresholding. To perform the segmentation of colored satellite images, authors proposed efficient and effective multilevel thresholding algorithms using different evolutionary algorithms [26] and nature inspired algorithms [27]. Very recently, in 2016 Pare et al. [28] proposed a novel energy curve based multilevel thresholding technique for the segmentation of color satellite images. The segmented results obtained were quite impressive and accurate.

Despite of various multilevel thresholding approaches discussed above which are based on non-parametric methods such as Otsu method, Kapur's entropy, Tsalli's entropy, etc., researches have been also focused on minimum cross entropy (MCE) function, due to its measurement accuracy in selecting threshold and simplicity to deal with the problem of multilevel image thresholding. MCE is developed using an information theoretic distance among the two probability distributions within the same set [29]. The optimal thresholds are gained by minimizing the cross entropy between the object and background. However, the computation time of MCE increases exponentially as the segmentation level increases. To reduce the computation complexity, deployment of meta-heuristic algorithms has been gaining huge popularity in the recent years. The successful application of DE [21], PSO [30], honey bee mating optimization [31], GA [32], ABC [33], and firefly algorithm (FA) [34] has been implemented in determining the optimal thresholds using MCE as an objective criterion. Such successful applications encourages further investigation in the feasibility of solving image segmentation through famous metaheuristic algorithm, namely CS algorithm.

Over the last few years, CS algorithm has flourished due to its optimum performance in the multilevel thresholding framework. This swarm-based algorithm solves the structural optimization problems in combination with *Lévy* flights [35]. The multilevel thresholding based studies illustrate that the CS algorithm is remarkably proficient and has reportedly outperformed other popular meta-heuristic algorithms reported in the literature. Authors in [36,37] reported the outstanding performance of CS among other meta-heuristic algorithms such as GA, PSO, ABC, DE, and Bacterial foraging optimization (BFO). CS has outperformed recently emerging FA in solving multilevel segmentation based problems [38]. CS has also performed better than WDO algorithm in performing the multilevel thresholding of satellite images [23]. A comparative performance study in [27] has depicted the outstanding performance of CS using different objective functions as compared to other optimization algorithms with respect to the color image multilevel thresholding. Recently, authors in [28] performed an extensive study on CS algorithm using energy curve based different entropy objective criterions. This paper has reported the accurate and robust performance of CS via *Lévy* flights as compared to ELR-CS in solving the color image segmentation problem via multilevel thresholding.

1.1. Motivation of the presented work

With advancements in digital media, segmentation of images confronts new challenges for image understanding and content analysis in various types of application-specific images such as natural images and remote sensing images. Several color images depict various complexities and multimodal histograms with uncertainties. Especially, multiband satellite images exhibits poor resolution, non-uniform illumination and complex background. [26]. Therefore, such images require more sophisticated multilevel thresholding approach to obtain accurate segmentation to extract the objects of interest. In literature, most of the techniques have been adopted only for segmentation of natural gray scale images. However, they are computationally costly and their effectiveness diminishes when used for complex image especially satellite images. Remote sensing or satellite images have wide range applications in various astronomical or geo-science related application. Satellite images are fundamental tool for analyzing and understanding different regions, fundamentally exploited for various environment based evaluation for an instance, in inspecting marine environment, forest resources monitoring, agriculture, climate survey, military, mapping, metrology, etc. [27]. From the literature, it can be seen that the segmented color images convey better as well as more information. But, segmentation of 3 band/channel images (Satellite/RGB) increases the computation complexities [28]. Moreover, the above mentioned techniques are concentrated thresholding technique using the popular objective function such as fuzzy entropy, between-class-variance, Kapur's entropy, Tsallis entropy, and Rényi's entropy etc.

This has motivated to develop efficient and effective technique to search optimal thresholds for multi-level thresholding of colored natural and satellite images. In this paper, multilevel MCE is minimized by the CS algorithm to generate optimum threshold values efficiently and accurately. Convergence of CS algorithm gains stable and interesting solutions. Experimental results over different test images reveal that the proposed technique successfully improves the efficiency of multilevel thresholding based segmentation, compared with similar methods such as ABC, BFO, DE and WDO. In addition, the proposed approach has gained better results as compared to thresholding techniques based on two more objective criterions between-class variance (Otsu method) and Tsalli's entropy function. The outcomes of proposed thresholding technique is validated for different threshold levels on the basis of performance evaluation metrics such as peak signal to noise ratio (PSNR), mean square error (MSE), feature similarity index (FSIM), structural similarity index (SSIM), and Computational time (CPU time). Fitness value, mean and standard deviation (*STD*) are also presented for comparison.

1.2. Structure of the paper

The following sections depict the whole architecture of this paper: Section 2 makes a general description of two different mul-