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An efficient cuckoo search algorithm based multilevel thresholding for segmentation of satellite images using different objective functions

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ABSTRACT

Satellite image segmentation is challenging due to the presence of weakly correlated and ambiguous multiple regions of interest. Several bio-inspired algorithms were developed to generate optimum threshold values for segmenting such images efficiently. Their exhaustive search nature makes them computationally expensive when extended to multilevel thresholding. In this paper, we propose a computationally efficient image segmentation algorithm, called $CS_{McCulloch}$, incorporating *McCulloch's* method for *lévy* flight generation in Cuckoo Search (CS) algorithm. We have also investigated the impact of *Mantegna's* method for *lévy* flight generation in CS algorithm ($CS_{Mantegna}$) by comparing it with the conventional CS algorithm which uses the simplified version of the same. $CS_{Mantegna}$ algorithm resulted in improved segmentation quality with an expense of computational time. The performance of the proposed $CS_{McCulloch}$ algorithm is compared with other bio-inspired algorithms such as Particle Swarm Optimization (PSO) algorithm, Darwinian Particle Swarm Optimization (DPSO) algorithm, Artificial Bee Colony (ABC) algorithm, Cuckoo Search (CS) algorithm and $CS_{Mantegna}$ algorithm using Otsu's method, Kapur entropy and Tsallis entropy as objective functions. Experimental results were validated by measuring PSNR, MSE, FSIM and CPU running time for all the cases investigated. The proposed $CS_{McCulloch}$ algorithm evolved to be most promising, and computationally efficient for segmenting satellite images. Convergence rate analysis also reveals that the proposed algorithm outperforms others in attaining stable global optimum thresholds. The experiments results encourages related researches in computer vision, remote sensing and image processing applications.

1. Introduction

Image segmentation approach aims to partition a given image into several homogeneous regions such that the union of no two adjacent regions are homogeneous (Pal & Pal , 1993). Satellite images are characterized by weak local correlation between pixels, complete randomness, and ambiguous regions and small multiple regions of interest which makes it difficult to segment. Aforementioned definition for segmentation makes us to think deep about the great difficulty in deciding the homogeneity measure which can be used to discriminate between the objects present in the image. Romshoo and Rashid (2014) reported the difficulty in extracting agricultural lands from satellite images owing to the poor illumination, poor resolution and adverse environmental conditions that prevail while capturing the images in their work based on modified on-field neural network (Romshoo & Rashid, 2014).

Optimization algorithms were developed with an intention to solve such complex problems where time and resources are limited. The uncertainty which persists in every real world systems further complicates the search for optimality. The search for optimal solutions of a particular problem is accomplished by a system of multiple agents which tends to evolve in each iteration obeying a set of laid out rules. The population thus evolved will exhibit some emergent characteristics which self-organizes the system leading to an optimal solution in the search space. Therefore, design of an efficient optimization algorithm is equivalent to mimicking the evolution of a self-organizing system.

Thus 'nature inspired man' to mimic life around him which paved way to the development of many meta-heuristic approaches for implementing optimization algorithms to solve complex problems (Coello, Van Veldhuizen, & Lamont, 2002; Hammouche, Diaf, & Siarry, 2010; Ouadfel & Meshoul, 2014). Several thresholding algorithms preceded this framework using various evolutionary techniques such as Genetic algorithm (Deb, Pratap, Agarwal, & Meyarivan, 2002; Tao, Tian, & Liu, 2003; Gallotta, 2007), Particle Swarm

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Optimization (PSO) algorithm (Kennedy & Eberhart,1995, 2010; Sathya & Kayalvizhi, 2010; Horng, 2011), Firefly algorithm (Yang, 2009; Horng & Jiang, 2010; Brajevic & Tuba, 2014), Ant Colony Optimization (ACO) algorithm (Dorigo et al., 1999; 2008; 2010; Tao, Jin, & Liu, 2007), Bacterial Foraging Optimization (BFO) algorithm (Passino,2002, Sathya and Kayalvizhi, 2011 Brabazon, ONeill, and McGarraghy, 2015;), Honey Bee Mating Optimization (HBMO) algorithm (Haddad, Afshar, & Mariño, 2006; Horng, 2010), Cuckoo Search (CS) algorithm (Yang & Deb, 2009; Bhandari, Singh, Kumar, & Singh, 2014; Brajevic & Tuba, 2014; Bhandari, Kumar, & Singh, 2015b) and Artificial Bee Colony (ABC) algorithm (Karaboga & Basturk, 2008; Horng, 2011; Hassanzadeh, Vojodi, & Moghadam, 2011; Karaboga, Gorkemli, Ozturk, & Karaboga, 2014).

As in the other domains, researches flourished in the area of image segmentation owing to the efficiency of meta-heuristic algorithms. Exhaustive search strategy employed by these algorithms to reach optimality proved to be computationally very expensive since the time requirement grew exponentially with the increase in the number of desired thresholding levels for image segmentation. Since computational time exists as a constraint in most of the real-world scenarios, numerous efforts were made to improve the convergence rate of these optimization algorithms.

Fractional order PSO (FODPSO) was applied for multi-spectral and hyper-spectral satellite image segmentation by Ghamisi, Couceiro, Martins, and Atli Benediktsson (2014) which consumed less computational time compared with conventional PSO algorithm (Ghamisi et al., 2014). But theoretical analysis proved FODPSO algorithm to be consuming more computational time than Cuckoo search algorithm due to its algorithmic complexity. Jordehi (2015) came up with an enhanced leader PSO approach which helped in alleviating the premature convergence problem of conventional PSO algorithm thereby improving the convergence rate to an extend (Jordehi,2015). Liu, Mu, Kou, and Liu (2015) suggested a modification for conventional PSO algorithm by employing two new strategies for exhaustive search of optimal thresholds (Liu et al., 2015). In this work, authors incorporated an adaptive inertial factor which helped to increase the search efficiency and convergence rate, and an adaptive population factor which helped in escaping from local optima. The algorithm was tested for 16 standard images utilizing 12 unimodal and multi-modal benchmark functions and compared with standard GA and PSO. But the results proved to be inferior for higher thresholding levels which is required in satellite image segmentation scenario.

An improved variant of firefly algorithm (FA) was proposed by Wang, Guo, Duan, and Wang (2014) which accelerated the convergence speed for many global numerical optimizations (Wang et al., 2014). The algorithm when tested on images gave less satisfactory results. Histogram based multilevel thresholding approach guided by firefly algorithm (FA) with Brownian distribution (BD) was proposed by Raja, Rajinikanth, and Latha (2014). The algorithm proceeded to the optimum threshold values by maximizing between class variance. The test results showed the improvement of the proposed method over the conventional firefly algorithm in terms of segmentation quality with slight reduction in computational time (Raja et al., 2014). A modified firefly algorithm incorporating diversity enhanced strategy for global exploration and neighborhood search strategy for improved local exploitation of solution space was put forward by Chen et al. (2016). It showed better performance than DPSO, DE (Differential Evolution) and FA algorithms for standard test images, but proved to be less efficient for satellite image segmentation at higher thresholding levels (Chen et al., 2016).

Akay in 2013 implemented PSO and ABC algorithm for multilevel image thresholding by optimizing Kapur's entropy function (Akay, 2013). But the algorithm was prone to premature convergence problem which restricted it from reaching its global optima. A new approach for multilevel image thresholding was proposed by Alihodzic and Tuba (2014) hybridizing the Bat algorithm using certain elements from DE and ABC algorithms (Alihodzic and Tuba, 2014). It improved convergence speed significantly compared to the conventional approach for 6 benchmark images chosen. But the proposed approach failed to yield promising results for complex scenarios like satellite image segmentation.

A computationally efficient multilevel thresholding scheme was proposed by Bhandari et al. (2015b) for segmenting multispectral satellite images by modifying the initialization phase of ABC algorithm which outperformed PSO, GA and standard ABC algorithms, but was inferior to CS algorithm (Bhandari et al., 2015b). Hyperspectral satellite image segmentation using Differential Evolution maximizing Renyi entropy function was proposed by Sarkar, Das, and Chaudhuri (2016). Even though it showed competitive performance for the hyper-spectral data set chosen, theoretical validation proved that the convergence characteristics of DE to be inferior to that of CS algorithm (Sarkar et al., 2016).

Brajevic and Tuba (2014) investigated the efficiency of two meta-heuristic algorithms, Cuckoo Search and Firefly algorithm, for multilevel image thresholding (Brajevic & Tuba, 2014). Performance validation was done employing Otsu's between class variance and Kapur's entropy measure as objective functions for each of these algorithm. Although both of them yielded superior results in comparison with PSO and DE, CS showed a slight upperhand in terms of convergence rate. Bhandari et al. (2014) presented a study on the performance of CS and WDO algorithm for multilevel image thresholding of satellite images maximizing kapur's entropy (Bhandari et al., 2014). WDO was found to be very effective in bi-level thresholding case, while the CPU time factor increased exponentially with multilevel thresholding. A chaotic map based scheme was introduced to improve the calculation precision of CS algorithm mainly for high-dimensional functions by Ouyang, Pan, Yue, and Du (2014). Even though it helped to reduce the premature convergence problem of CS algorithm , but the presence of constant terms in exploration and exploitation phases of CS algorithm biased it to a greater extend which got reflected in stability and convergence speed analysis Ouyang et al., 2014. In 2015 Wang et al. published his work illustrating the use of chaotic maps in all these phases of CS algorithm which bought considerable improvement in the solution space (Wang & Zhong, 2015). Bhandari, Kumar, and Singh (2015a) presented a new CS based color image segmentation technique supported by Tsallis entropy, in which the authors have suggested the parameter q being the tuning factor for deciding the threshold values for segmentation (Bhandari et al., 2015a). Authors pointed out the major limitation of their algorithm to be its increased computational complexity.

Agrawal, Panda, Bhuyan, and Panigrahi (2013) published an extensive study on multilevel segmentation based on Cuckoo Search algorithm (Agrawal et al., 2013). Kurban, Civicioglu, Kurban, and Besdok (2014) have published an extensive and deep study on various swarm intelligence and evolutionary optimization approaches for color image thresholding. All these literatures highlighted the convergence characteristics of Cuckoo Search algorithm in comparison with others in the same line up. Another major advantage of CS algorithm is the requirement of less number of tuning parameters as compared with other bio-inspired optimization algorithms. Theoretical analysis also suggests the updation equations of Cuckoo Search algorithm satisfies global convergence properties. This guarantees the convergence of CS algorithm to its global optimum solutions, whereas the other algorithms even though converges quickly, but not necessarily to its global best. The efficient local and global search capabilities of cuckoo search algorithm made us to focus more on improving its performance for satellite image segmentation.