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Hyper-spectral image segmentation using Rényi entropy based multi-level thresholding aided with differential evolution

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ABSTRACT

This article presents a novel approach for unsupervised classification of land cover study of hyper-spectral satellite images to improve separation between objects and background by using multi-level thresholding based on the maximum Rényi entropy (MRE). Multi-level thresholding, which partitions a gray-level image into several distinct homogeneous regions, is a widely popular tool for segmentation. However, utility of multi-level thresholding is yet to be investigated in challenging applications like hyper-spectral image analysis. Differential Evolution (DE), a simple yet efficient evolutionary algorithm of current interest, is employed to improve the computation time and robustness of the proposed algorithm. The performance of DE is also investigated extensively through comparison with other well-known nature inspired global optimization techniques. In addition, the outcomes of the MRE-based thresholding are employed to train a Support Vector Machine (SVM) classifier via the composite kernel approach to improve the classification accuracy. The final outcomes are tested on popular hyper-spectral imagery like ROSIS and AVRIS sensors. The effectiveness of the proposed algorithm is evaluated through qualitative and quantitative comparison with other state-of-the-art global optimizers.

1. Introduction

Image thresholding i.e. the process of dividing an image into object(s) and background, is often considered as one of the most challenging and intriguing segmentation techniques. With advances of digital media, image segmentation faces new challenges in the form of content analysis and image understanding for various types of application-specific images, for example medical images (e.g. MRI, PET images), remotes sensing images (e.g. hyper-spectral images, SAR images) (Ham, Chen, Crawford, & Ghosh, 2005) and natural images (Panagiotakis, Grinias, & Tziritas, 2011). With the advances of remote sensing instruments, hyper-spectral images gain a lot of importance for plausible solution in many application like land-cover study, assessment of forest resources, flood monitoring, soil erosion monitoring, etc. Hyper-spectral images provide both detailed structural and spectral information as the sensors capture the radiance of various objects in a very large number of adjacent spectral channels. Hyper-spectral images are particularly very useful in object classification due to the enrich information contents. Also this large dimensionality creates lots of problem in practice (curse of dimensionality) such as the Hough phenomena (Hughes, 1968). Efficient segmentation of hyper-spectral images still remains a challenging issue.

In literature, several image segmentation techniques, such as gray level thresholding, interactive pixel classification, neural network based approaches, edge detection, and fuzzy rule based segmentation have been reported in Chanda and Majumder (2000), Fu and Mui (1981), Pal and Pal (1993), Sahoo et al. (1988), Zhang, Fritts, and Goldman (2008). Among these methods, gray level global thresholding techniques have drawn a considerable amount of attention among researchers and many algorithms have been proposed in this direction, see e.g. the works of Kapur, Sahoo, and Wong (1985), Li and Lee (1993), Otsu (1979), Pal (1996), Rosin (2001) and Wong and Sahoo (1989).

On the other hand, entropy-based schemes are counted as one of the most favored global thresholding methods. Segmentation done via bi-level thresholding subdivides an image into two homogenous regions based on texture, histogram, edge etc. Image segmentation, done via multi-level thresholding splits the image into different classes by selecting multiple threshold points. Both bi-level and multi-level thresholding methods can be classified into parametric and nonparametric approaches. In the parametric

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approaches, the gray-level distribution of each class has a probability density function that is generally assumed to be Gaussian. Parametric approaches attempt to find an estimate of the parameters of this distribution that will best fit the given histogram data (Kittler & Illingworth, 1986; Pun, 1981). This typically leads to a nonlinear optimization problem the solution of which is computationally expensive and time consuming. The nonparametric approaches can be based on an exploration of the threshold values by optimizing an objective function such as the between-class variance (Otsu's function; Otsu, 1979) and entropy (Kapur's function; Kapur et al., 1985). The non-parametric approaches gained popularity as because of they are computationally faster than parametric techniques.

Entropy-based global thresholding scheme has received the attention of several researchers, working on segmentation. With the advances in information theory, the opportunities to investigate use of various entropies to find efficient separation between objects and background have intensified. Some of the related methods have achieved huge popularity among the researcher such as Shannon entropy, Rényi entropy (Sahoo & Arora, 2004; Sahoo, Wilkins, & Yeager, 1997), Tsallis entropy (Portes de Albuquerque, Esquef, & Mello, 2004), cross entropy (Li & Tam, 1998), etc.

Principal assumption of the entropy-based global thresholding methods stands on expressing the entropy of the image histogram as a summation of two regions – the object(s) and the background. Entropy, a measurement of randomness, gained popularity in the field of pattern recognition on the idea that homogeneous regions will have minimum randomness and other region will have maximum randomness. The total maximum entropy of the image will indicate better separation between objects and background. The thresholds are being selected by minimizing/maximizing the total entropy between the original image and the resulting image. Let I be an original grayscale/color image and $P(i),\ i = 1, 2, ..., L$ be the normalized histogram of the corresponding image. L is indicating the number of gray levels. Then the resulting image I_t can be expressed as:

$$I_t(x,y) = \begin{cases} \mu(1,t) & if\ I(x,y) < t \\ \mu(t, L+1) & if\ I(x,y) \geq t \end{cases} \tag{1}$$

Where t = selected threshold which divides the image into two regions (object and background) and $\mu(a,b) = \sum_{i=a}^{b-1} iP(i)/\sum_{i=a}^{b-1} P(i)$.

The entropy based thresholding can be cast as a complex optimization problem. It should be taken into account that all the above mentioned techniques are for bi-level thresholding. A more practical approach for image thresholding is to consider multiple levels, so that the image may be divided into more than one objects and background. In spite of all its encouraging outcomes, multi-level thresholding techniques have a drawback in terms of its computation time and working complexity (Kittler & Illingworth, 1986; Wang, Chung, & Xiong, 2008). Researchers usually incorporate various methods as an alternative to these exhaustive search processes to enhance the computational speed of multi-level thresholding, see for example works like (Arora, Acharya, Verma, & Panigrahi, 2008; Sezgin & Taşaltín, 2000; Yu, Dong, Ogunbona, & Li, 2008; Zahara, Fan, & Tsai, 2005). Researchers are very often attracted by the quest of formulating total entropy as an objective function and solving it by using global optimization algorithms (Hammouche, Diaf, & Siarry, 2010).

Nature-inspired metaheuristics provide a very popular way to yield near optimal solutions to a wide variety of complex optimization problems without needing the knowledge of derivatives or without being sensitive to the choice of initial solutions. Derivative-free metaheuristic optimizers, based on the simulations of some natural phenomena, have been receiving a significant attention from researchers for segmenting images through both bi-level and multi-level thresholding. Applications of some well-known metaheuristics like Genetic Algorithms (GAs) (Hammouche, Diaf, & Siarry, 2008; Tang, Yuan, Sun, Yang, & Gao, 2011), Particle Swarm Optimization (PSO) (Akay, 2013; Yin, 2007), Artificial Bee Colony (ABC) (Bhandari, Kumar, & Singh, 2015b; Xiao, Cao, Yu, & Tian, 2012). Differential Evolution (DE) (Sarkar & Das, 2013; Sarkar, Das, & Chaudhuri, 2015; Sarkar, Patra, & Das, 2011), cuckoo search (Agrawal, Panda, Bhuyan, & Panigrahi, 2013; Bhandari et al., 2015a), etc. can be found in literature for segmentation and thresholding. It has been shown that DE can outperform state-of-art metaheuristics like GA and PSO when it is used for multi-level thresholding based image segmentation (Sarkar & Das, 2013; Sarkar et al., 2015).

Very recently application of multi-level of thresholding using evolutionary algorithms for segmenting satellite images became a popular area of research and metaheuristics like cuckoo search (CS) using Otsu's function, Tsallis and Kapur's entropy (Bhandari, Kumar, & Singh, 2014, 2015a), modified artificial bee colony (MABC) using Tsallis entropy (Bhandari, Kumar, & Singh, 2015b) and fractional-order Darwinian PSO (FODPSO) using Otsu's function (Ghamisi, Couceiro, Martins, & Atli Benediktsson, 2014) were proposed in this direction.

The key contribution in this work consists design of computationally faster, robust and accurate unsupervised segmentation technique. Additionally a novel scheme of supervised classification is also conceptualized where the segmented output image is used to train the classifier to obtain higher classification accuracy. In this paper an unsupervised multi-level thresholding is accomplished by exploiting the Rényi entropy and the DE algorithm. The results of this algorithm are evaluated against state-of-the-art global optimizers like GA, PSO, ABC, and CS on real hyper-spectral images collected by popular imaging sensors like AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) and ROSIS (Reflective Optics System Imaging Spectrometer). Performances of the employed metaheuristics are compared on the basis of convergence speed and average computational time, mean objective value and standard deviation. Additionally two widely popular statistical tests namely Wilcoxon's rank sum test and Analysis of Variance (ANOVA) are used for the same purpose. To demonstrate applicability of the proposed scheme, the outcomes of the unsupervised segmentation are used as input to a supervised classifier (in this case SVM) to achieve better classification accuracy. Comparisons of final classification map, achieved by different multi-level thresholding using various global optimizers along with the SVM classifier are also undertaken. SVM classifier is one of the most widely used classifiers for hyper-spectral image segmentation. Here in this paper a composite kernel based SVM (SVM-CK) is employed to combine segmentation output and SVM (Jun, Reddy, Plaza, Bioucas-Dias, & Atli Benediktsson, 2013).

The paper is organized in the following way. Section 2 briefly describes the proposed approach along with the formulation of a detailed objective function using Rényi entropy and DE along with supervise classification. Dataset, experimental setup and performance evolution functions are and covered in Section 3. Experimental results of applying the proposed method to the hyper-spectral data along with statistical analyses and comparison with other metaheuristics and classification are provided in Section 4. Finally the paper is concluded in Section 5.

2. Proposed methodology

The algorithm presented in this paper is divided into two parts. In the first part an unsupervised approach of multi-level Rényi entropic thresholding aided with a global optimizer (in our case DE) is employed on hyper spectral images. A Volume-Gradient-based Band Selection method (VGBS) specially designed for Hyper-spectral images (Geng, Sun, Ji, & Zhao, 2014) is applied to find the most significant band (Fig. 1).