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An improved biogeography based optimization approach for segmentation of human head CT-scan images employing fuzzy entropy

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ABSTRACT

The present paper proposes the development of a three-level thresholding based image segmentation technique for real images obtained from CT scanning of a human head. The proposed method utilizes maximization of fuzzy entropy to determine the optimal thresholds. The optimization problem is solved by employing a very recently proposed population-based optimization technique, called biogeography based optimization (BBO) technique. In this work we have proposed some improvements over the basic BBO technique to implement nonlinear variation of immigration rate and emigration rate with number of species in a habitat. The proposed improved BBO based algorithm and the basic BBO algorithm are implemented for segmentation of fifteen real CT image slices. The results show that the proposed improved BBO variants could perform better than the basic BBO technique as well as genetic algorithm (GA) and particle swarm optimization (PSO) based segmentation of the same images using the principle of maximization of fuzzy entropy.

1. Introduction

It is a well known fact that image segmentation is considered an important preprocessing step in development of sophisticated and complex image processing algorithms. Among image segmentation techniques, thresholding based techniques and especially multilevel thresholding based techniques enjoy a lot of popularity among researchers all over the world. However, obtaining efficient performance utilizing multilevel thresholding always poses a great challenge as the cost of misclassification of pixels can be of paramount importance, depending on the image(s) under consideration. Depending on the application at hand, the minute level of detailed segmentation, and hence extraction, to be achieved, keeps on changing (Jain, 1989; Gonzalez and Woods, 2000; Pal and Pal, 1993). Hence, segmentation problems may require that the image intensity histogram be classified using a single threshold (as in bi-level thresholding), using two thresholds (as in three-level thresholding) or using more than three thresholds. However, the robust, automatic determination of these thresholds, to produce high performance segmented images, still remains a challenging problem in the domain of image segmentation.

There have been several methods, proposed so far, for multilevel thresholding based image segmentations (Kapur et al., 1985; Otsu, 1979; Pun, 1980; Yin, 1999; Brink, 1994; Li et al., 1995; Cheng and Lui, 1997; Tobias and Seara, 2002; Huang and Wang, 1995; Cheng et al., 1998; Saha and Udupa, 2001; Hu et al., 2006; Tao et al., 2007, 2003; Zhao et al., 2001; Sahoo et al., 1988). Many of these methods are based on maximization of entropy, used as a measure to determine high quality of segmentation performed. Most of these schemes attempt to optimize an objective function to achieve optimal thresholding such that the thresholded classes achieve some desired characteristic. Some of these methods attempt to maximize posterior entropy to measure homogeneity of segmented classes (Kapur et al., 1985; Brink, 1994; Cheng et al., 1998; Saha and Udupa, 2001). In (Otsu, 1979), Otsu proposed a very popular method of image segmentation by maximizing the separability between different segments using Euclidean distance based between-class variance. Another popular method attempted to maximize the upper bound of the posterior entropy, derived from the histogram, developed by Pun (Pun, 1980). In Saha and Udupa (2001), thresholds were determined by jointly maximizing the class uncertainty and the region homogeneity.

Several thresholding techniques have also been proposed based on index of fuzziness, fuzzy similarity measure and fuzzy entropy (Li et al., 1995; Cheng and Lui, 1997; Tobias and Seara, 2002; Huang and Wang, 1995; Cheng et al., 1998; Tao et al., 2007, 2003; Zhao et al., 2001). In this decade, the principle employing fuzzy entropy has emerged as a popular measure for thresholding

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based image segmentation. A fuzzy entropy is a function on fuzzy sets whose measure varies with the sharpness of its argument fuzzy set (Tao et al., 2003). Researchers have used the concept of fuzzy entropy in different ways, for the purpose of image segmentation. In Cheng et al. (1998), the concept of fuzzy logic was implemented to calculate fuzzy homogeneity vectors that involve the spatial uncertainties among image pixels. In Cheng et al. (2000), a new approach to fuzzy entropy was proposed which was utilized for automatic determination of fuzzy regions of membership functions. In this paper, we utilize an approach developed latter for implementing fuzzy entropy principle, proposed in (Tao et al., 2007, 2003), which was inspired by the algorithm proposed in Zhao et al. (2001). This fuzzy entropy measure is developed utilizing fuzzy *c*-partition (FP) and the probability partition (PP) and deals with measuring the compatibility between these two indices.

In most of these entropy based methodologies, the desired criterion is to find the optimum of each such measure, as a function of the optimum threshold intensity gray levels. The stochastic optimization techniques, employing population-based methodologies, have been proven as successful algorithms for optimizing entropy based measures, in recent times, to solve such optimization problems. Several such candidate algorithms have been reported utilizing genetic algorithm (GA) (Yin, 1999; Tao et al., 2003; Cheng et al., 2000), ant colony optimization (ACO) (Tao et al., 2007), particle swarm optimization (PSO) (Maitra and Chatterjee, 2008), bacterial foraging optimization (BFO) (Maitra and Chatterjee, 2008) etc. The present paper proposes the development of a three-level thresholding algorithm maximizing fuzzy entropy, utilizing a very recently proposed population-based algorithm, called biogeography based algorithm (BBO) (Simon, 2008). The BBO algorithm mimics the natural phenomenon of migration of species from one geographical area (called "island" or "habitat") to another geographical area, how new species are created and how species become extinct. The suitability of each habitat is evaluated on the basis of a habitat suitability index (*HSI*). Like in other population based algorithms, *HSI* plays the role similar to objective function and each habitat plays the role of a candidate solution. The *HSI* of each habitat depends on its constituent features (like each individual variable/dimension in a population based stochastic optimization algorithm) and each such feature is called a suitability index variable (*SIV*). The objective is to determine the best habitat (which is actually a combination of several *SIV*s), for which the *HSI* is maximum. To achieve this goal, each habitat of the population is subjected to "migration" and "mutation" procedures, generation after generation, until the termination criterion is satisfied. In our work we have proposed some modifications of the basic BBO algorithm to achieve improved performance. We propose to implement nonlinear variations of immigration rate and emigration rate (discussed later) with species count in a habitat, as opposed to the common idea of linearly varying these two factors with species count in basic BBO algorithm.

The present paper proposes the development of a new optimal three-level thresholding algorithm, utilizing basic BBO algorithm and its proposed improved variants for real CT scan images obtained from the human head. The methods utilize maximization of a fuzzy entropy criterion to determine these optimal thresholds. The computed tomography (CT) scanning is a well known diagnostic tool for scanning interior portions of our body. It helps the physicians with the views of internal body structures. A CT scan procedure facilitates creation of multiple cross-sectional image slices on a cathode-ray tube (CRT), obtained by passing X-rays through our body. Head CT scans are used for several purposes like examining the brain, detecting the sinuses, detecting bleeding, brain injury and skull fractures, detecting a blood clot, detecting a stroke etc. We have tested our algorithms for a series of image slices captured from a volunteer head. A comparison of segmentation performances of improved BBO variants show they could largely outperform the performances of basic BBO algorithm, and of two other popular population-based algorithms, namely, genetic algorithm (GA) and particle swarm algorithm (PSO).

The rest of the paper is organized as follows. Section 2 presents a short pre-amble on CT scan and gives a description of our system for capturing real images from CT scans of human head. Section 3 describes the very recent biogeography-based optimization strategy. Section 4 presents our proposed modifications to the basic BBO. Section 5 presents the fuzzy entropy criterion based measure employed for optimal three-level thresholding. Performance evaluation is presented in detail in Section 6. Conclusions are presented in Section 7.

2. The CT scan

A CT scan is a short form for computerized tomography. The method employs digital geometry processing technique to produce a 3D image of the interior structure of a body, utilizing a large series of 2D X-ray images, taken around a single axis of rotation. It is basically an X-ray technique but differs from the conventional X-ray examinations. In CT scan, we obtain images of our body that visualize internal structures in cross section, which is in contrast to the conventional X-ray examinations which produce overlapping images. In conventional X-ray technique, a stationary X-ray machine is used to focus beams of radiation on a particular area of our body to produce two-dimensional images on film or a digital detector. But a CT scan system is equipped with an X-ray unit that rotates around our body and is connected to a computer-based acquisition system. Hence a CT scan produces a set of cross-sectional image slices of the interior of our body. A CT scan is usually prescribed to have clear view of the bones and organs and the inner structures of our abdomen, liver, stomach, intestines, kidney, pancreas, adrenal glands, etc.

A CT scan of the head is usually conducted to detect (i) bleeding, brain injury and skull fractures, (ii) a blood clot, (iii) a stroke, (iv) brain tumors, (v) diseases/malformations of the skull, (vi) to evaluate the extent of bone and soft tissue damage in patients, (vii) to plan radiation therapy for cancer of the brain or other tissues, (viii) to guide the passage of a needle used to obtain a tissue sample (biopsy) from the brain etc. (Online). Since its introduction in the 1970s, CT has become an important tool in medical imaging to supplement X-rays and medical ultrasonography. Although it is still quite expensive, it is the gold standard in the diagnosis of a large number of different disease entities.

There are several advantages that CT has over traditional two-dimensional medical radiography, which make them such a popular choice (Online). One of the premier advantages is that CT can completely eliminate the superimposition of images of structures outside the area of interest. The second prominent feature is that because of the inherent high-contrast resolution of CT, differences between tissues that differ in physical density by less than 1% can be distinguished. The third advantage presents us with the flexibility that a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task. Although CT scanning has so many advantages to boast off, it remains a moderate to high radiation diagnostic technique.

For our work, the images were acquired from the CT scan of the head of a volunteer in Henri Mondor Hospital, in Créteil, Paris, France. The image acquisition system employed was a famous