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Image contrast enhancement using an artificial bee colony algorithm

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ABSTRACT

The objective of image contrast enhancement is to improve the contrast level of images, which are degraded during image acquisition. Image contrast enhancement is considered as an optimization problem in this paper and the *artificial bee colony* (ABC) algorithm is utilized to find the optimal solution for this optimization problem. The contribution of the proposed approach is two-fold. First, in view of that the fitness function is indispensable to evaluate the quality of the enhanced image, a new objective fitness function is proposed in this paper. Second, the image transformation function is critical to generate new pixel intensities for the enhanced image from the original input image; more importantly, it guides the searching movements of the artificial bees. For that, a parametric image transformation function is utilized in this paper so that only the optimal parameters used in the transformation function need to be searched by the ABC algorithm. This is in contrast to that the whole space of image intensity levels is used in the conventional ABC-based image enhancement approaches. Extensive experiments are conducted to demonstrate that the proposed approach outperforms conventional image contrast enhancement approaches to achieve both better visual image quality and higher objective performance measures.

1. Introduction

Image contrast enhancement aims to improve the contrast level of images, since the image quality can suffer due to several factors, such as contrast, illumination and noise during image acquisition procedure. Image contrast is defined as the separation factor between the brightest spot and the darkest spot in images [1]. A larger separation factor indicates higher contrast; on the other hand, the smaller separation factor indicates lower contrast. Image contrast enhancement is useful in many real-world application areas. For example, the high-quality photographic images can be produced by embedding this technology into the digital camera to handle low light image acquisition environment [2].

In view of the importance of the image contrast enhancement technology, many algorithms have been developed in the literature. A widely used image enhancement method in the spatial domain is called histogram equalization, which can be further improved by the adaptively modified histogram equalization [3]. It scales the magnitudes of the probability density function of the original input image before applying histogram equalization. The scaling factor is adaptively adjusted according to the averaged image intensity values of the image. The non-parametric modified histogram equalization effectively handles the histogram spikes and reduces the distortion in smooth regions without the empirical adjustment of parameters [4,5]. The image intensity values can also be adjusted based on various contrast and sharpness measure [6]. In addition, gray transformation function can be also combined with evolutionary algorithms [7–11] to process low-quality images. These evolutionary algorithms are utilized to search for the optimal mapping of the gray levels of the input image into new gray levels, so that the image contrast is enhanced [12].

In recent years, many bionic algorithms have been developed for image enhancement, such as bat algorithm [13], cuckoo algorithm [14], and immune algorithm as follows [15]. In [13], the neuron network and bat algorithm is combined, where the bat algorithm has been applied to tune the parameters of the modified neuron model for the maximization of two competitive image performance indices contrast enhancement factor and mean opinion score. In [14], the enhanced cuckoo algorithm and optimum wavelet is utilized to perform medical image enhancement by selecting the optimum scale value of the wavelet. The improved algorithm can adaptive rebuilding the worst nests. Fitness of each nest is estimated for all iterations and the threshold value is fixed based on the fitness value. An improved

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immune algorithm is proposed in [15] to enhance MRI images. The main improvement of this approach is divided into three points. Firstly, instead of the simple binary coding, the real coding approach of the MRI brain image is designed. Secondly, the mutation distance is added into the mutation operator to better control the mutation progress and avoid any narrow local optimization. Finally, both the clone selection and the mutation are adjusted together in the Gauss distribution, the uniform distribution, and the chaotic distribution, rather than in only the Gauss distribution. The above three papers are all designed for enhancing the medical image, but the evaluation criteria for image quality has not been described in detail.

Recently, the *artificial bee colony* (ABC) technique has been introduced into tackling the image contrast enhancement problem, motivated by the fact that the ABC technique is an effective optimization tool for solving the objective optimization problem [16,17]. The ABC algorithm is motivated by the intelligent behavior of the honey bees. It can provide a population-based search procedure, where the food positions (i.e., image intensity values in the context of image contrast enhancement) are evaluated and modified by the artificial bees in the iterations, and the artificial bees aim to discover the optimal food sources places (i.e., the best enhanced image in the context of image contrast enhancement) [18,19]. Yimit et al. [20] exploits a grayscale transformation function using local gray-level distribution in the neighborhood of each pixel of the image. Draa and Bouaziz [21] proposes to use the ABC technique to find the optimal image solution based on a new gray-level mapping technique and a new image quality measure. Joshi and Prakash [22] proposes to incorporate the direction constraints into the conventional ABC algorithm so that artificial bees can move adaptively to obtain better solution. They also add a new contrast-based quality estimation into the objective function of the ABC algorithm. Bhandari et al. proposes a wavelet-domain image enhancement approach, where the ABC technique is employed to learn the parameters of the adaptive thresholding function required for optimal image contrast enhancement [23].

This paper proposes a new ABC-based image contrast enhancement approach. The proposed approach has the following two contributions, which are significantly different with conventional ABC-based image contrast enhancement approaches.

- First, a new objective fitness function is proposed in this paper with the incorporation of a new image contrast measure. The spatial neighborhood information of the image is critical to enhance the image contrast [24]. However, such spatial information is neglected in conventional ABC-based image contrast enhancement approaches. In view of this, a new image contrast measure is incorporated into the cost function of the proposed approach. The proposed new fitness function consists of four performance measures: (i). sum of edge intensities; (ii). number of edge pixels; (iii). entropy of the image; and (iv). image contrast. This fitness function automatically measures the quality of the produced image; consequently, it determines the quality of the enhanced image. Therefore, the artificial bees are guided by this new cost function to find the optimal transformation function.
- Second, a parametric image enhancement method is utilized in the proposed approach, rather than searching for optimal pixel values in the whole image intensity space. Conventional ABC-based approaches treat image contrast enhancement in the spatial domain, by using a transformation function that produces a new intensity for each pixel of the original image to generate the enhanced image. Intuitively, if the image resolution increases, the size of the solution space for the artificial bees will increase. Consequently, the time complexity of the algorithm will increase hugely. To overcome this challenge, the proposed approach exploits a parametric image enhancement method, more specifically, the *Incomplete Beta Function* (IBF) [25], which has been proven to be effective in image contrast enhancement [26]. The solution space has a smaller size is compared with that of image intensity levels for all pixels in the image.

The rest of this paper is organized as follows. A brief introduction to the conventional ABC algorithm is presented in Section 2. A new ABC-based image contrast enhancement approach is proposed in Section 3. The proposed approach is evaluated in Section 4 in extensive experiments. Finally, Section 5 concludes this paper.

2. Artificial bee colony algorithm

A brief introduction to the ABC algorithm is provided in this Section. The ABC algorithm is a swarm-based metaheuristic for solving numerical optimization problems [16]. This metaheuristic is inspired by the intelligent foraging behavior of natural honeybees. The population in an artificial bee colony is subdivided into three subgroups: (i). employed bees; (ii). onlooker bees; and (iii). scout bees. These artificial bees move in a search space and choose food sources, which are possible solutions to the target optimization problem.

To be more specific, the employed bees are responsible for studying various food sources and sharing the information with the onlooker bees. The food source that yields higher score and higher quality will have a larger chance to be selected by onlooker bees. On the other hand, those food sources with lower marks will have smaller chances to be selected. The food source could also be rejected due to its low quality. In this case, the scout bees will conduct the random search for new food sources. Therefore, in each cycle of searching iteration, three steps are involved: (i). the employed bees are sent to search the food sources and measure their quality; (ii). the food sources are selected by the onlookers after sharing the information with the employed bees; (iii). the scout bees are sent to search for new possible food sources, if certain food sources are rejected due to low quality.

The aforementioned ABC algorithm is briefly described as below.

- *Initialization stage*: Every solution of the bee colony is initialized, and the fitness of each solution is measured.
- Iteratively perform the following steps until the maximum number of iterations is reached or the stop condition is satisfied.
  – *Employed bee stage*: A new solution is produced by the employed bee, which randomly moves in the neighbor of its current solution. The new generated solution will replace the old solution, if it yields a better fitness value.
  – *Onlooker bee stage*: After all employed bees have completed their works, each onlooker bee probabilistically selects a solution according to its fitness value of the solution.
  – *Scout bee stage*: A solution will be abandoned if its fitness value has not been improved for a given number of generations. Then a new solution is re-generated using the initialization method.
- The solutions are updated using the greedy criteria, and the best solution and its corresponding fitness value are recorded.

3. Proposed ABC-based image contrast enhancement approach

3.1. Motivation and challenges of using ABC algorithm in image contrast enhancement

The ABC algorithm is a stochastic technique used for searching for optimal solutions of a combinatorial optimization problem. Basically, its idea is to assign artificial bees to examine the search space to search for feasible solutions. Moreover, these artificial bees collaborate and exchange information so that bees concentrate on more promising solutions in terms of the fitness functions.

The ABC algorithm is exploited in this paper to address image contrast enhancement problem due to the following motivations. The image contrast enhancement optimization problem is regarded as a