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New quantum inspired meta-heuristic techniques for multi-level colour image thresholding

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ABSTRACT

The efficient meta-heuristic techniques, called ant colony optimization, differential evolution and particle swarm optimization, inspired by the fundamental features of quantum systems, are presented in this paper. The proposed techniques are Quantum Inspired Ant Colony Optimization, Quantum Inspired Differential Evolution and Quantum Inspired Particle Swarm Optimization for Multi-level Colour Image Thresholding. These techniques find optimal threshold values at different levels of thresholding for colour images. A minimum cross entropy based thresholding method, called Li's method is employed as an objective (fitness) function for this purpose. The efficiency of the proposed techniques is exhibited computationally and visually on ten real life true colour images. Experiments with the composite DE (CoDE) method, the backtracking search optimization algorithm (BSA), the classical ant colony optimization (ACO), the classical differential evolution (DE) and the classical particle swarm optimization (PSO), have also been conducted subsequently along with the proposed techniques. Experimental results are described in terms of the best threshold value, fitness measure and the computational time (in seconds) for each technique at various levels. Thereafter, the accuracy and stability of the proposed techniques are established by computing the mean and standard deviation of fitness values for each technique. Moreover, the quality of thresholding for each technique is determined by computing the peak signal-to-noise ratio (PSNR) values at different levels. Afterwards, the statistical superiority of the proposed techniques is proved by incorporating Friedman test (statistical test) among different techniques. Finally, convergence curves for different techniques are presented for all test images to show the visual representation of results, which proves that the proposed Quantum Inspired Ant Colony Optimization technique outperforms all the other techniques.

1. Introduction

Till date, segmentation has turned out to be one of the most admired techniques in digital image processing. Assuming an image as a region, it can be effectively used to divide the given region into a number of homogeneous and disjoint subregions. There must have at least one attribute in common in each subregion, which may include texture, colour or any other feature. So far, image segmentation technique has been successfully applied in various domains of applications. Some of them may include face detection [1], image retrieval [2] and object recognition [3] to name a few. Thus far, plentiful segmentation techniques are available in the literature. A detailed review of different segmentation methods has been presented in [3]. As we know that a colour pixel is a mixture of three different colour components, some additional computational complexities may arise for colour image segmentation.

From the last few decades, thresholding has been used as an image segmentation tool which is usually exploited to extract an object from its background image. The success behind the ongoing popularity of image thresholding is assumed to be its intrinsic simplicity, exactitude and robustness. The simplest form

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of thresholding is called bi-level thresholding where the number of non-overlapping regions is taken as exactly two. The bi-level thresholding can be extended into the multilevel version with an added computational complexity. The number of subregions are selected according to the number of threshold values to be computed in multilevel thresholding. Presently, a number of thresholding techniques are available in the literature [4,5]. Kirby and Rosenfeld [6] presented a 2D entropic thresholding technique based on the image pixels and their neighbouring pixels. Another two entropy based thresholding techniques have been proposed by Abutaleb [7] and Pal and Pal [8]. Both of these proposed techniques find the posterior entropies of the segmented regions for bi-level thresholding. According to their mathematical observation, the maximization of the sum of calculated entropy values possesses the optimal threshold values. Their proposed techniques proved to be computationally time inefficient, which was later reduced to $O(L^{8/3})$ (L being the grey levels of an image) by another 2D entropic thresholding technique proposed by Chen et al. [9]. Gong et al. [10] presented another recursive algorithm in 1998. The authors developed a 2D entropic thresholding technique. It has been observed that the computational complexity of their proposed technique could be successfully reduced to $O(L^2)$. Over the last few years, the most popular and widely used thresholding techniques are Pun's method [11], Kapur's method [12], Otsu's method [13] to name a few. Sezgin and Sankur presented a comprehensive report on image thresholding techniques in [14].

These days, optimization is widely used in diversified branches of application. Thus far, the researchers in artificial intelligence, computer science and engineering and many other associated fields, have successfully applied different optimization techniques in an assortment of applications. An optimization technique aims to find the best combination of possible solutions within a rational time period. In its way, it optimizes the given fitness function (objective function) considering all the constraints (if any) for optimum solutions. Meta-heuristics are well-known stochastic and heuristic optimization practices, which are basically used to solve various optimization problems. Sometimes, an additional learning strategy is adopted in few cases to expand their dedicated search space. Thereby it augments the performance of such meta-heuristic problems. The meta-heuristics explore their search space to find the optimal solutions of the given problem. Simulated annealing, particle swarm optimization, tabu search, ant colony optimization etc. are very popular and widely used meta-heuristics techniques. In the literature, the renowned meta-heuristics techniques have been applied frequently to develop new algorithms in multidimensional faces. A few such examples are presented in [15–19].

Ant colony optimization (ACO) [20], differential evolution (DE) [21] and particle swarm optimization (PSO) [22] have been successfully used as effective optimization tools in image segmentation. Tao et al. [23] proposed an entropy-based segmentation technique using ACO in 2008. The authors compared their proposed technique with some other comparable techniques to show the effectiveness and the acceptability of the proposed system. Dorigo and Gambardella have presented a learning approach using ant colony system. They have used travelling salesman problem for experimental purpose [24]. The experimental results show that their proposed method outperforms other comparable methods. Later, Chu et al. [25] proposed few communication strategies using ant colony system. They proved that their proposed system works better than the existing similar systems. Thus far, a number of authors have successfully used ant colony optimization to develop variety of applications, which include data mining [26], quadratic assignment problem [27], space-planning [28], discrete optimization for graph colouring and job-shop scheduling [29] to name a few. Zahara et al. [30] used hybrid optimization approach to propose a multi-level thresholding technique in 2005. Later, in 2007, another PSO based multi-level thresholding technique using minimum cross entropy has been developed by Yin [31]. In recent years, DE has been successfully implemented in various domains. The superiority of DE over another meta-heuristics is established in different research works by the number of researchers [32]. A dichotomization technique for multilevel thresholding has been proposed by Sezgin and Tasaltin [33] to find the optimal threshold values for inspection applications.

Since the last few years, Quantum Computing (QC) has been successfully applied in a variety of applications in computer science and engineering, artificial intelligence and many other fields [34,35]. Gradually, the popularity of QC has exponentially increased to the scholars of diversified fields. Basically, the features of quantum mechanics are the source of originality of QC. The parallelism capability in QC helps to reduce the algorithmic complexity remarkably [36–38]. The inherent physical effects of QC may be exploited using some hardware devices. When such devices are designed, they are called quantum computers [35]. After the exhaustive study by Feynman [39], QC became a subject of interest for many researchers. Since the eighteenth century, it has been turned into one of the most increasingly interesting research area in different fields of application. Many quantum inspired algorithms have been developed till date. An automatic object extraction technique has been presented by Aytekin and Gabbouj [40]. The authors have introduced the basic quantum theory in their proposed technique. Gao et al. [41] developed a PSO based quantum-behaved algorithm for multi-level thresholding. They have proved that their proposed method is more efficient than the existing methods. Sun and Xu [42] used the basic quantum mechanical features into particle swarm optimization to develop a quantum-behaved algorithm. They have showed that their proposed algorithm is easy to control and provides encouraging results than the existing PSO. Hogg [43] has proposed a quantum searching framework using Grover's algorithm. In his proposed framework, the quantum gate performance was evaluated compliant with the respective cost. Thereafter, an extended version of the previous framework was presented by Hogg and Portnov [44]. The authors have proposed an quantum inspired algorithm for combinatorial optimization. Han et al. [45] also presented a quantum inspired evolution algorithm (QIEA) to solve the knapsack problem. The performance of universal artificial neural networks (ANN) has been increased to a larger extent using the basic quantum features. A few examples of such applications have been presented in [46,47]. In 2002, Li and Zhuang [48] have presented a quantum inspired genetic algorithm where, the quantum crossover and quantum mutation have been performed using a probability criteria to guarantee a faster convergence. Zhang et al. [49] proposed a quantum evolutionary algorithm (QEA) using genetic algorithm for filter design. So far, few quantum inspired meta-heuristic algorithms for image thresholding have been proposed in the literature. Some bi-level image thresholding methods have been presented in [34,50,51]. Later, Dey et al. developed six different quantum inspired meta-heuristic techniques for multi-level image thresholding for real grey-scale images [52]. Quantum inspired meta-heuristic techniques for multi-level colour image segmentation have also been presented in [37,53].

In this paper, three new quantum inspired meta-heuristic techniques have been developed using different approaches, which are suitable for multi-level colour image thresholding. These proposed techniques employ ant colony optimization, differential evolution and particle swarm optimization separately and the fundamental features of quantum computing (QC) to couple into suitable algorithmic structure. These are Quantum Inspired