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Efficient quantum inspired meta-heuristics for multi-level true colour image thresholding

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ABSTRACT

Thresholding is a commonly used simple and effective technique for image segmentation. The computational time in multi-level thresholding significantly increases with the level of computation because of exhaustive searching, adding to exponential growth of computational complexity. Hence, in this paper, the features of quantum computing are exploited to introduce four different quantum inspired meta-heuristic techniques to accelerate the execution of multi-level thresholding. The proposed techniques are Quantum Inspired Genetic Algorithm, Quantum Inspired Simulated Annealing, Quantum Inspired Differential Evolution and Quantum Inspired Particle Swarm Optimization. The effectiveness of the proposed techniques is exhibited in comparison with the backtracking search optimization algorithm, the composite DE method, the classical genetic algorithm, the classical simulated annealing, the classical differential evolution and the classical particle swarm optimization for ten real life true colour images. The experimental results are presented in terms of optimal threshold values for each primary colour component, the fitness value and the computational time (in seconds) at different levels. Thereafter, the quality of thresholding is judged in terms of the peak signal-to-noise ratio for each technique. Moreover, statistical test, referred to as Friedman test, and also median based estimation among all techniques, are conducted separately to judge the preeminence of a technique among them. Finally, the performance of each technique is visually judged from convergence plots for all test images, which affirms that the proposed quantum inspired particle swarm optimization technique outperforms other techniques.

1. Introduction

Segmentation can be defined as a fundamental maneuver towards partitioning images into number of uniform, non-overlapping and homogeneous regions. In [1], Haralick et al. have demonstrated some important features which a noble image segmentation should expose in regard to gray-level images. The pixels in each region shares at least a very few similar attributes comprising colour, texture or even the intensity values. There must be some divergent characteristics in the adjacent regions. Since the last decade, segmentation is progressively becoming very popular in different image processing and computer vision oriented applications. Usually, a colour pixel is manifested as a concoction of dissimilar colour constituents. The fusion of different colour components in colour images may enhance an immense amount of inherent computational complexities with regard to colour image processing. Hence, it turns more challenging to espouse them in real life. Some typical applications of image segmentation may include locating tumours [2], face recognition [3] and image retrieval [4] to name a few.

Image segmentation has turned out to be a prevalent subject of interest for many researchers. Over the last few decades, an intensive research has been accomplished with reference to image segmentation. A detailed review on different segmentation techniques have been reported in [5]. Unlike the existing segmentation techniques introduced so far, thresholding has proven itself to be the most popular as well as the most efficient method due to its inherent characteristics. It is simple to implement and provides accurate results in image segmentation. It can be introduced as an effectual tool to separate images into object and its corresponding background [6]. Based on the number of threshold values, it is called either of bi-level and multilevel thresholding. For bi-level

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image thresholding, a single threshold value is used to divide the entire image into exactly two groups. Multiple threshold values can be used to divide the image into minimum three groups in multi-level thresholding. In this category, number of groups yielded is one more than the number of threshold selected for image thresholding. Since, higher level of thresholding requires more computations, the time complexity of algorithms increase proportionately with the increase in the level of thresholding in multilevel thresholding. Both of these two versions of image thresholding can be acclimated by exploiting either of parametric and nonparametric approaches [7,8].

For the period of last few decade, Quantum Computing (QC) has turned out to be an upcoming field in computer science and engineering [9,10]. Gradually, it has persuaded a comprehensive exploration by many researchers. The concept QC has been originated by exploiting the principles of quantum physics. The parallelism that the quantum computing provides, reduces obviously the algorithmic complexity [11–13]. Such an ability of parallel processing can be used to solve efficiently optimization problems. The quantum theory acknowledge the instinctive physical effects like interference, entanglement, superposition, which can be strapped up to accomplish astounding operations using data element of QC. When such computer devices are designed to utilize these mammoth quantum effects, it is named quantum computers [10]. The system able to amass and coherently process information in a Hilbert space.

The practice of meta-heuristics can be expressed as heuristic search optimization procedures, which basically espouse some high level learning stratagems to explore search path for having near optimal solution. Meta-heuristics are innately stochastic and generally domain independent. The performance of meta-heuristic can be hastened by adjoining some supplementary components, if necessary. A few examples of meta-heuristics may include tabu search, simulated annealing, evolutionary algorithms, particle swarm optimization, and ant colony optimization to name a few. From the last few decades, these meta-heuristic algorithms have been used in different facet, some of them are given in [14–18]. Some quantum inspired meta-heuristic algorithms for bi-level image thresholding have been presented in [9,19,20]. Later, six quantum behaved meta-heuristic algorithms have been developed for multi-level image thresholding for gray-scale images [21]. Some authors have proposed different quantum inspired meta-heuristic algorithms for Multi-level Thresholding for colour images [12,22]. In this paper, an extended version of the above mentioned algorithms [12,22] have been presented with different approach for colour images. The proposed methods namely, Quantum Inspired Genetic Algorithm (QIGAMLTCI), Quantum Inspired Simulated Annealing (QISAMLTCI), quantum inspired differential evolution (QIDEMLTCI) and finally, quantum inspired particle swarm optimization (QIPSOMLTCI) are designed to find the optimal solution (near-optimal) for multi-level thresholding for colour image. Though few quantum inspired meta-heuristic techniques are already available these days, the proposed algorithms have different significant values in global multi-level thresholding.

In this paper, Kapur's function [23] and Huang's function [24] have been separately employed as the objective functions to find the predefined number of optimal threshold values for colour images. Since a colour image encompasses basic three colour components, the population of participating agents is formed with three qubit encoded strings of length $\sqrt{L}$, each. Here, L is the maximum pixel intensity value among the three basic colour components in the image. The comparative study has been conducted among the proposed techniques and their conventional methods. Finally, Friedman test and median based estimation have been performed to find the superior technique among themselves.

As the comparative study, to judge the effectiveness and supremacy of the proposed techniques, six different methods viz., backtracking search optimization algorithm (BSA) [25], composite DE (CoDE) method [26], the classical genetic algorithm [27], the classical simulated annealing [28], the classical differential evolution [29] and also the classical particle swarm optimization [30] for multi-level thresholding, have been introduced for experimental purpose.

The organization of the paper is as follows. The literature survey about the related works has been presented in Section 2. The fundamentals of quantum computing is described elaborately in Section 3. A brief scenario about the motivation of the proposed work has been presented in Section 4. In Section 5, the relevant discussion on the basis of quantum algorithm, have been presented. Section 6 describes details of the objective functions which have been used for experimental purpose. The details of the proposed techniques are explained in Section 7. The experimental results in different forms are reported in Section 8. Finally, in the conclusion part, some pertinent conclusions have been made for the proposed technique in Section 9.

2. Background

Yin and Chen [31] combined a neighbourhood searching approach and the traditional genetic algorithm (GA) to develop a new algorithm for multilevel thresholding. They have tried to accelerate the optimization of their proposed algorithm. But due to some inherent weakness of GAs, the algorithm lacks in finding its optimal stability for higher convergent speed. Another approach to speed up multilevel threshold optimization and to increase optimal stability, was taken up by Cao et al. [32]. They have successfully introduced a learning operator (GA-L) into GA for this purpose. In 2008, Tao et al. [33] have presented another object segmentation technique using fuzzy entropy with the popular ant colony optimization (ACO) method. Another two techniques on multi-level thresholding have been presented in [34,35]. Ratnaweera et al. presented a PSO based study in [36] where the authors showed that an assortment in population in PSO algorithm is obligatory to escape from trapping in local optima and reach at global optima. Jiao et al. have developed algorithm on classification where the authors have worked on organizational coevolutionary algorithm in 2006 [37]. Luo et al. have developed algorithm on image segmentation [38]. They have used colony images for their experimental purpose. In their proposed algorithm they have successfully combined the features of (SA–GA) to reduce the individual's weaknesses to have better results. Another coalesced version of meta-heuristic algorithm using genetic algorithm and simulated annealing has been presented by Fengjie et al. in [39]. They have used 2D Otsu method in images having low contrast. Tang et al. have presented another algorithm based on SA and improved Snake model for image segmentation [40]. Nakib et al. have proposed a different work on non-supervised image segmentation for multi-objective optimization [40]. Sezgin and Tasaltin have presented a new technique for multilevel thresholding [6]. They have applied the proposed technique for inspection applications.

Since the last few decades, quantum computing has gradually become one of most popular research fields in computer science and engineering. The theory of quantum computation has been flourished by an intensive study of Feynman [41]. A number of researchers introduced the concept of quantum computation in several artificial neural networks (ANN) to enhance their effectiveness [42,43]. Narayan and Moore used the theory of quantum computing in the conventional genetic algorithm to modify its crossover operation [44]. Furthermore, another improved quantum version of genetic algorithm have been presented by Li and Zhuang

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