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Multi-level thresholding using quantum inspired meta-heuristics

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ABSTRACT

Image thresholding is well accepted and one of the most imperative practices to accomplish image segmentation. This has been widely studied over the past few decades. However, as the multi-level thresholding computationally takes more time when level increases, hence, in this article, quantum mechanism is used to propose six different quantum inspired meta-heuristic methods for performing multi-level thresholding faster. The proposed methods are Quantum Inspired Genetic Algorithm, Quantum Inspired Particle Swarm Optimization, Quantum Inspired Differential Evolution, Quantum Inspired Ant Colony Optimization, Quantum Inspired Simulated Annealing and Quantum Inspired Tabu Search. As a sequel to the proposed methods, we have also conducted experiments with the two-Stage multi-threshold Otsu method, maximum tsallis entropy thresholding, the modified bacterial foraging algorithm, the classical particle swarm optimization and the classical genetic algorithm. The effectiveness of the proposed methods is demonstrated on fifteen images at the different level of thresholds quantitatively and visually. Thereafter, the results of six quantum meta-heuristic methods are considered to create consensus results. Finally, statistical test, called Friedman test, is conducted to judge the superiority of a method among them. Quantum Inspired Particle Swarm Optimization is found to be superior among the proposed six quantum meta-heuristic methods and the other five methods are used for comparison. A Friedman test again conducted between the Quantum Inspired Particle Swarm Optimization and all the other methods to justify the statistical superiority. Finally, the computational complexities of the proposed methods have been elucidated for the sake of finding out the time efficiency of the proposed methods.

1. Introduction

Image thresholding can be recognized as the easiest and most efficient method that is widely used for image segmentation. This is used as an effective tool to bifurcate images into object and background [1]. For its first kind, the pixel intensities of the image are grouped into two classes, called bi-level image thresholding. While the number of groups exceed two, it is recognized as multi-level thresholding [2]. Both of them can be identified by acclimatizing parametric or nonparametric approaches [3,4]. Moreover, there exists different algorithms for bi-level image thresholding that can also be extended to their corresponding multi-level versions, if necessary [2,5]. When the level increases in multi-level thresholding, the number of computations increase as well. This could add significant difficulties specially when higher level threshold values are evaluated. Many algorithms have been proposed so far that can handle this situation efficiently, where some of them are developed for a specific purpose. These algorithms have their own advantages and disadvantages. However, in this paper, six new quantum meta-heuristic methods for multi-level thresholding are presented that can be used efficiently for general purpose.

Generally a wave function, $|\psi\rangle$ which exists in Hilbert space, is employed for describing a quantum system. The Schrödinger equation (SE) is assumed to be accountable for overseeing the inherent dynamism of quantum computing (QC). A quantum bit or *qubit* is considered as the smallest unit for a two-state quantum machine. The qubit may be in "0" state or in "1" state or even in superposition between these two states where, $|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ and $|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$. The superposition of the two state vectors are symbolized by the

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equation $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ where, α, β are complex numbers satisfying the equation $|\alpha|^2 + |\beta|^2 = 1$. Coherence in QC exists when the states are in superposed form maintaining a constant phase relationship between them. When the coherence is forced to be destroyed, decoherence occurs. For decoherence, the requisite probability for collapsing to the state $|1\rangle$ and $|0\rangle$ are $|\alpha|^2$ and $|\beta|^2$, respectively. Quantum entanglement is a fascinating feature in quantum system that can be employed to describe the correlations between the diversified qubits [6,7]. Quantum entanglement of a quantum state can be demonstrated using the density matrix [6,7]. Entanglement can be analyzed, distorted, and even washed out, if required, [6,8]. Quantum interference is an another interesting feature of a quantum system. The advancement of new research era advocates the researchers to entrench the algorithmic construction of different quantum-inspired evolutionary algorithms (QIEA) by incorporating the philosophy of quantum system [9]. So far, a number of combinatorial optimization problems have been resolved using QIEA, where the concept of wave interference was introduced [8]. Han et al. designed an QIEA where the qubit with some probability constraints, linear superposition between states and various Q-gates for population assortment have been used [9].

Nowadays, meta-heuristic approaches are widely used in various domains of engineering and science. Many authors have utilized different meta-heuristic approaches for image thresholding. Some distinctive applications of meta-heuristic are given in [10–14]. Mostly, the traditional approaches of multi-level thresholding for gray scale images use binary encoding scheme, where each pixel is represented by 8 bits. Thus, the length of the string increases in multiply of 8 for higher levels. As this article is confined on gray scale images, this fact motivated us to propose an alternative technique based on quantum inspired meta-heuristic methods for multi-level thresholding using the notion of qubits, where real value encoding scheme is used to determine the active pixel. For this purpose, $\sqrt{L}$ number of random pixels are selected, where, L represents the maximum pixel intensity value of the gray scale test image. With this encoding scheme, Quantum Inspired Genetic Algorithm (QIGA), Quantum Inspired Particle Swarm Optimization (QIPSO), Quantum Inspired Differential Evolution (QIDE), Quantum Inspired Ant Colony Optimization (QIACO), Quantum Inspired Simulated Annealing (QISA) and Quantum Inspired Tabu Search (QITS) for multilevel thresholding are proposed. The effectiveness of these methods is demonstrated on fifteen images at the different level of thresholds in terms of different quantitative measures. Thereafter, consensus results of these six methods are also computed. Finally, statistical test, called Friedman test [15,16], is conducted to judge the superiority of a method among them.

As a part of comparative study to adjudge the efficacy of the proposed quantum inspired methods, we have resorted to five classical algorithms viz., Two-Stage Multithreshold Otsu method (TSMO) [17], Maximum Tsallis entropy Thresholding (MTT)[2] [18], Modified Bacterial Foraging (MBF) algorithm [19], classical Particle Swarm Optimization for multi-level thresholding [20] and classical Genetic Algorithm for multi-level thresholding [21]. The comparative study reveals that the Quantum Inspired Particle Swarm Optimization outperforms the proposed five quantum meta-heuristic methods and the other five classical algorithms used for comparison.

2. Background

The field of quantum computing became popular since the notion of quantum mechanical system was anticipated at the early 1980s [22]. The aforesaid quantum mechanical machine is able to solve some particular computational problems awfully efficiently [23]. In [24], the author has recognized that classical computer faces lack of ability while simulating quantum mechanical system. The author has presented a structural framework to build quantum computer. Alfares et al. analyzed how the notion of quantum algorithms can be applied to solve some typical engineering optimization problems [25]. According to their perception, some problems may arise when the features of QC are applied. These problems can be avoided by using certain kind of algorithms. Hogg has presented a framework for structured quantum search where Grovers algorithm was applied to correlate the cost with the gate's behavior [26]. In [27], the authors have extended the work and proposed a new quantum version of combinatorial optimization. Rylander et al. presented a quantum version of genetic algorithm where the quantum principles like superposition and entanglement were employed on modified genetic algorithm. In [28], Moore et al. proposed a framework for general quantum-inspired algorithms. Later, Han et al. [9] developed an evolution algorithm which was applied for solving knapsack problem. In their paper, basic quantum principles like qubits and rotation quantum gate were used. Afterward, in [9], the authors have designed another version of quantum inspired evolutionary algorithm by Han et al. where the performance was evaluated according to the angles of the rotation gates and later, in [29], a new improved version of this algorithm was presented. They divided the evolution stage into two different phases and proposed alteration to the quantum gate adding a termination criterion. The improved version of the work presented in [9] was proposed by Zhang et al. where they applied a different approach to get the best solution [30]. Narayan et al. presented a genetic algorithm where quantum mechanics was used for modification of crossover scheme [31]. Moreover, Li et al. developed a modified genetic algorithm using quantum probability representation. They adjusted crossover and mutation processes for attaining the quantum representation [32]. In [33], the authors presented a quantum-inspired neural network algorithm where also the basic quantum principles were employed to symbolize the problem variables.

The instinctive compilation of information science with the quantum mechanics resort to construct the concept of quantum computing. Quantum evolutionary algorithm (QEA) was admired as a probability based optimization technique. It uses qubits encoded strings for its quantum computation paradigm. The intrinsic principles of QEA help to facilitate for maintaining the equilibrium between exploitation and exploration. In recent years, some researchers have presented some QEAs to solve particular combinatorial optimization problems. A typical example of QEA is Filter design by Zhang et al. [34]. The researches are still going on to create purposeful and scalable quantum computers.

Meta-heuristic optimization techniques are employed heuristically in searching algorithms. They use iterative approach to have better solution by fleeing from local optima. So they coerce some basic heuristic to compensate from local optima. There are some renowned Meta-heuristic techniques namely, GA, PSO, DE, ACO, SA and TS which are applied for optimization with different manners. Holland has proposed genetic algorithms (GAs) which impersonate the belief of some natural fruition. GAs can be applied efficiently in data mining for classification. In 2006, Jiao et al. presented organizational coevolutionary algorithm for classification (OCEC) [35]. In OCEC, bottom-up searching technique has been adopted and enthused from the coevolutionary model that can efficiently knob multi-class learning. Kennedy and Eberhart first proposed Particle Swarm Optimization (PSO) in 1995 inspiring from the synchronized movement in flocks of birds [36]. In PSO, the population of particle is the particle swarm. In 2004, Sousa et al. projected PSO in data mining [37]. PSO can be skilfully used in

[2] As abbreviated in [18].