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A quantum inspired gravitational search algorithm for numerical function optimization

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ABSTRACT

Gravitational search algorithm (GSA) is a swarm intelligence optimization algorithm that shares many similarities with evolutionary computation techniques. However, the GSA is driven by the simulation of a collection of masses which interact with each other based on the Newtonian gravity and laws of motion. Inspired by the classical GSA and quantum mechanics theories, this work presents a novel GSA using quantum mechanics theories to generate a quantum-inspired gravitational search algorithm (QIGSA). The application of quantum mechanics theories in the proposed QIGSA provides a powerful strategy to diversify the algorithm's population and improve its performance in preventing premature convergence to local optima. The simulation results and comparison with nine state-of-the-art algorithms confirm the effectiveness of the QIGSA in solving various benchmark optimization functions.

1. Introduction

Quantum mechanics, also known as quantum physics, is a branch of physics which provides a mathematical description of wave-like behavior and interaction of material and energy. Quantum mechanics differs considerably from classical mechanics in its domain when the scale of observations becomes comparable to the atomic and sub-atomic scale, called quantum realm.

Based on the concepts and principles of quantum mechanics, in the early 1980s, quantum computing is proposed by Feynman [6,7]. Afterward, because of its powerful computational performance, there has been a great interest in the application of the quantum computing [40,29]. Quantum computation is based on some principles of quantum theory, such as the superposition of quantum states, collapsing into one state, entanglement; the application of various properties of quantum physics toward building a new kind of computers. Quantum computers have been progressed actively, in order to solve some specialized issues that classical computers have some adversity by facing with them [29,8]. It is declared that quantum computing has the ability of solving many difficult problems in the field of classical computation.

It is worth noticing that if there is no quantum algorithm to solve practical problems, the quantum computer hardware becomes useless. Quantum algorithms exploit the laws of quantum mechanics in order to perform efficient computation within a less time compared to classical algorithms. Nevertheless, such efficiency is granted when the algorithm is run on a quantum computer, whereas the simulation on a classical computer can be very time-consuming. By now, only a few quantum algorithms are known, however, it has been shown that quantum computation can greatly improve performance for solving such problems like factoring [5] or searching in an unstructured database [11].

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Nowadays, heuristic search algorithms have been widely employed to solve global optimization problems. Heuristic search algorithms are stochastic algorithms that mimic the processes of natural phenomena such as natural selection, natural evolution, and self-organization. These algorithms maintain a collection of potential solutions for a problem. Some of these possible solutions are used to create new potential solutions through the use of specific operators. The operators act on population and produce collections of new potential solutions at each iteration. This process is used repeatedly to generate new collections of potential solutions till the stopping criterion is met [32]. It is shown that the population-based heuristic search algorithms are effective and flexible tools to solve the problems in a wide range of application [23,25,19,15,36].

Since the late 1990s, many various heuristic approaches have been adopted by researches, such as genetic algorithm (GA) [52], simulated annealing (SA) [24], ant colony optimization (ACO) [4], particle swarm optimization (PSO) [18], artificial bee colony algorithm [1], and GSA [32]. One of the newest algorithms is GSA; it is a global search strategy that can handle efficiently arbitrary optimization problems. Rashedi et al. introduced the GSA in 2009; it is based on the Newtonian laws of gravity and motion [17]. The basic idea of the GSA is to mimic the physical attraction between masses. Many researchers have used the GSA to solve various problems. The obtained results confirm the high performance of GSA in solving various problems [32].

In standard GSA, an object/agent is depicted by its mass and position vector which determines the trajectory of the objects. The object moves along a determined trajectory while in quantum, the term trajectory is meaningless, since the position of a particle cannot be determined due to the uncertainty principle [16]. The above considerations indicate that the merging between the two novel computing paradigms, namely heuristic search algorithms and quantum mechanics, can be beneficial. In recent years, researchers have focused on quantum inspired heuristic search algorithms [54,55].

Since introducing the quantum computing, many quantum-based algorithms are proposed which are classified into two groups: (i) one concentrates on generating new quantum algorithms for using of quantum computer and (ii) other one concentrates on the quantum-inspired heuristic search algorithms.

The first attempts on the first group have been started since the early 1990s. Several significant quantum algorithms including the quantum search algorithm [11], quantum factorization algorithm [39] and quantum genetic programming [44,30] have been proposed to show that quantum computers are more powerful than classical computers at least with respect to solving some specific problems [45].

Some researchers in this approach have tried to propose the new heuristic search algorithms for quantum computers, which is called heuristic search designed quantum algorithms (HDQs) [43,20,9,10,34]. HDQs are able to discover new algorithms for quantum computers [42]. In order to check the capability of HDQs, a quantum computer is simulated, so that the ability of a quantum algorithm can be determined on classical hardware. Nowadays, because of inaccessibility of quantum computers, quantum algorithm is not useful. In this perspective, having a quantum version of heuristic search algorithms seems to be a related topic in the future, when quantum computers will be available.

The other researches in the second group concentrate on quantum-inspired heuristic search algorithms (QIHSAs) for a classical computer; a branch of study on heuristic search algorithm that is characterized by certain principles of quantum mechanics or computation such as standing waves, entanglement, and collapse.

Two kinds of algorithms have been identified:

(i) *Quantum computing-inspired heuristic search algorithms (QCHs)*: QCHs concentrate on generating new heuristic search algorithms using some concepts and principles of quantum computing such as standing waves [26], interference [56], coherence [31], qubits, superposition, quantum gates and quantum measurement, in order to solve various problems in the context of a classical computing model [26]. Like a quantum mechanical system, a quantum-inspired system can be regarded as a probabilistic system, in which the probabilities related to each state are utilized to describe the behavior of the system.

QCHs are firstly introduced by Narayanan and Moore in the 1990s to solve the traveling salesman problem [27]; in their proposed algorithm the crossover operation uses the concept of interference. The contribution of Narayanan and Moore [27] indicate the potential advantage of introducing quantum computational parallelism into the population-based algorithm framework. No further attention is paid to QCHs until an algorithm is proposed by Han and Kim [13,14]. Their proposed algorithm uses a Q-bit representation instead of binary or numeric representations. On the other hand, this algorithm tries to simulate parallel computation in classical computers.

(ii) *Heuristic search algorithms based on quantum mechanics principles (HQMs)*: These algorithms concentrate on using quantum mechanics in heuristic search algorithms. In this group of experience every particle is assumed in quantum space. The individual particle of quantum system moves in a quantum multi-dimensional space. The state of a particle is depicted by wave function $\Psi(x, t)$, instead of position and velocity.

Like a quantum mechanical system, HQMs can be considered as a probabilistic system, in which the probabilities related to each state are utilized to describe the behavior of the system. More specifically, wave functions are applied to represent agent individuals. Agents are moved in quantum search space to find the optimum. In order to generate new population, the agent and fitness evaluation are linked by a probabilistic observation process.

The first version of HQMs named QPSO is introduced by Sun et al. in 2004 [47], in which the particles of a PSO system are assumed in quantum space based on the concept of quantum mechanics. In [47] the authors proposed an approach based on classical PSO that each particle assumed in quantum search space with a potential well (with center of P).