Improved Bloch Quantum Genetic Algorithm Based on Elite Strategy

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INTRODUCTION

Heuristic optimization algorithms are a vital part of optimization theory, where researchers draw inspiration from natural environments and incorporate biological behaviors into models. Currently, a multitude of evolutionary algorithms have been proposed domestically, such as Genetic Algorithms (GAs), Immune Algorithms, and Ant Colony Optimization, among others, which are all intelligent optimization methods. Evolutionary algorithms fundamentally mimic the process of biological systems, where populations adapt to environments, interact, and continuously optimize, thereby embodying characteristics of swarm intelligence.

In 2006, Li Shiyong and Li Panchi proposed the Double Chains Quantum Genetic Algorithm (DCQGA), which encodes chromosomes using quantum bits, describes feasible solutions using quantum bit probability amplitudes, and updates quantum bits using quantum rotation gates, thus avoiding the measurement of quantum bits.

Although DCQGA and BQEA greatly expand the number of optimal solutions, they also enlarge the search space, increasing the difficulty of search. Therefore, this paper proposes a novel improved Bloch Elite Quantum Genetic Algorithm (BEQGA) by introducing the concept of elitism. To validate the effectiveness of the algorithm, ten commonly used test functions are selected for experimentation, and experimental results are compared and analyzed against the basic Bloch Quantum Genetic Algorithm.

METHOD

In the basic Bloch Quantum Genetic Algorithm, during the process where regular individuals converge towards the optimal individual, the rotation angle is fixed. This can lead to excessive rotation angles in the later stages of the search, potentially causing the algorithm to miss the optimal solution. Therefore, we introduce perturbation factors and adaptive adjustment factors. The specific operations are as follows:

$$\text{Let } p_i = \begin{bmatrix} \cos\varphi_{i1}\sin\theta_{i1} & \dots & \cos\varphi_{in}\sin\theta_{in} \\ \sin\varphi_{i1}\sin\theta_{i1} & \dots & \sin\varphi_{in}\sin\theta_{in} \\ \cos\theta_{i1} & \dots & \cos\theta_{in} \end{bmatrix},$$

Let the gene values of the m-th dimension of individual p be X_1, Y_1, Z_1, and let the gene values of the optimal individual in the m-th dimension be X_2, Y_2, Z_2.

$$A=-\text{sign}\left(\begin{vmatrix} X_1 & X_2 \\ Y_1 & Y_2 \end{vmatrix}\right),\ B=-\text{sign}(Z_2 - Z_1)$$

In the traditional Bloch Quantum Genetic Algorithm, regular individuals only converge towards the optimal individual, which can easily lead to local optima[9]. To address this, we expand the number of elite individuals to multiple. Each individual randomly selects elite individuals for comparison; if the individual is better, it replaces the elite individual, otherwise, it converges towards that elite individual. This way, regular individuals do not all converge towards a single individual, effectively reducing the risk of falling into local optima.

RESULTS

To validate the effectiveness and superiority of the improved Bloch Quantum Genetic Algorithm in solving function optimization problems, the following test functions are selected for experimentation and comparison with the Simple Genetic Algorithm (SGA).

$$f_1(x) = 10D + \sum_{i=1}^{D} x_i^2 - 10\cos(2\pi x_i)$$

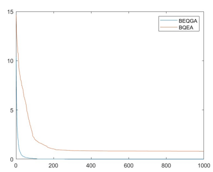
$$f_2(x) = -20\exp\left(-0.2\sqrt{\frac{1}{D}\sum_{i=1}^{D} x_i^2}\right) - \exp\left(\frac{1}{D}\sum_{i=1}^{D}\cos(2\pi x_i)\right) + 20 + \exp(1)\ (x)$$

$$f_3(x) = \left(\sum_{i=1}^{D} x_i^2\right)^{0.25} \left(\sin^2\left(50\left(\sum_{i=1}^{D} x_i^2\right)^{0.1}\right) + 1\right)$$

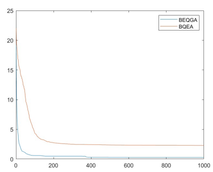
$$f_4(x) = 1 - \frac{\cos^2\left(\sqrt{\sum_{i=1}^{D} x_i^2}\right) + 1}{2 + 0.5\left(\sum_{i=1}^{D} x_i^2\right)}$$

$$f_5(x) = -\sum_{i=1}^{D} \frac{x_i^2}{4000} + \prod_{i=1}^{D} \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$$

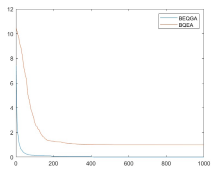
Function	Items	BEQGA	BQEA
$f_1(x)$	Best Solution	0	0.0196
	Worst Solution	4.3245e-04	4.0137
	Average	1.0944e-05	0.8437
	Variance	3.8286e-09	0.6717
$f_2(x)$	Best Solution	1.8407e-12	0.0279
	Worst Solution	0.5440	2.3295
	Average	0.0133	0.8234
	Variance	0.0059	0.2646
$f_3(x)$	Best Solution	8.7962e-04	0.2401
	Worst Solution	0.2400	1.1785
	Average	0.0491	0.4329
	Variance	0.0022	0.0205
$f_4(x)$	Best Solution	2.2204e-16	0.0125
	Worst Solution	0.0638	0.2142
	Average	0.0579	0.06791
	Variance	3.2672e-04	0.0010
$f_5(x)$	Best Solution	0.0025	0.0044
	Worst Solution	0.0074	0.0347
	Average	0.0030	0.0117
	Variance	1.5566e-06	3.2486e-05



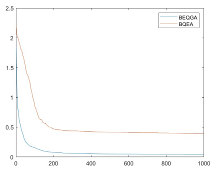
Comparison Chart of $f_1(x)$



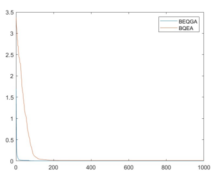
Comparison Chart of $f_2(x)$



Comparison Chart of $f_3(x)$



Comparison Chart of $f_4(x)$



Comparison Chart of $f_5(x)$

DISCUSSION

In the optimization process of BQEA, individuals only converge towards the optimal individual, and the rotation angle is fixed, which can easily lead to local optima. To address this issue, a new Bloch Quantum Genetic Algorithm (BEQGA) was proposed by expanding the number of elite individuals and improving the optimization method of fixed rotation angles. Through multiple simulation experiments and comparisons, the BEQGA algorithm has shown certain improvements in search accuracy and convergence speed compared to the BQEA algorithm. This provides strong support for the research of key technologies for high-precision flexible bag packaging equipment.

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