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Hybrid parallel chaos optimization algorithm with harmony search algorithm☆

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ABSTRACT

The application of chaotic sequences can be an interesting alternative to provide search diversity in an optimization procedure, named chaos optimization algorithm (COA). Since the chaotic motion is pseudo-randomness and chaotic sequences are sensitive to the initial conditions, the search ability of COA is usually effected by the starting values. Considering this weakness, parallel chaos optimization algorithm (PCOA) is studied in this paper. To obtain optimum solution accurately, harmony search algorithm (HSA) is integrated with PCOA to form a novel hybrid algorithm. Different chaotic maps are compared and the impacts of parallel parameter on the hybrid algorithm are discussed. Several simulation results are used to show the effective performance of the proposed hybrid algorithm.

1. Introduction

Chaos has been applied in many scientific fields since the first introduction of canonical chaotic attractor in 1963 by Lorenz [1]. Chaos is a bounded unstable dynamic behavior that exhibits sensitive dependence on its initial conditions [2]. An essential feature of the chaotic systems is that small changes in the parameters or the starting values lead to the vastly different future behaviors. Recently, chaotic sequences have been adopted instead of random sequences to provide the search diversity in an optimization procedure, named chaos optimization algorithm (COA) [2–7]. Due to the non-repetition of the chaos, the COA can carry out overall searches at higher speeds than stochastic ergodic searches that depend on the probabilities. The COA, which has the features of easy implementation, short execution time and robust mechanisms of escaping from the local optimum, is a promising optimization tool for the engineering applications [2–7]. Recently, in most of those literatures, researchers have considered integrated use of chaotic sequences in order to enhance the performance of the meta-heuristics algorithms, such as chaotic harmony search algorithm [8,9], chaotic ant swarm optimization [10–12], chaotic particle swarm optimization [13–21], chaotic genetic algorithms or chaotic evolutionary algorithm [22–26], chaotic differential evolution [27–29], chaotic firefly algorithm [30], chaotic simulated annealing [31,32], hybrid COA with artificial emotion [33].

Since the chaotic motion is pseudo-randomness and chaotic sequences are sensitive to the initial conditions, COA's search ability is usually effected by the starting values. So, a kind of parallel chaotic optimization algorithm (PCOA) is proposed in our former study [34,35], which shows its superiority over general COA. In the PCOA, multiple chaotic maps are simultaneously mapped onto one decision variable, so PCOA searches from diverse initial points and can detract the sensitivity of initial condition. Although the hybrid algorithm based on PCOA in [34,35] can reach optimum solutions, the search speed is slow since the employed local search technique – simplex search method has slow efficiency.

Harmony search algorithm (HSA) [36–38], first introduced to optimize various continuous nonlinear functions by Geem et al. [36], is one of the latest evolutionary computation techniques, mimicking the musical process of search for a perfect state of harmony. In comparison to other meta-heuristics, the HSA imposes fewer mathematical requirements and can be easily adapted, furthermore, numerical comparisons demonstrated that the evolution in HSA is faster than genetic algorithm [39]. Recently, several improvements have been presented to HSA, such as chaotic harmony search algorithm [8,9] and improved HSA [38–41].

In this paper, to obtain optimum solution accurately, HSA is integrated with PCOA to form a novel hybrid optimization algorithm.

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The proposed hybrid algorithm is a two stages search technique, the first stage is the PCOA with twice carrier wave parallel chaos search for global searching, and the second stage is the HSA for accurate local searching. In the proposed hybrid algorithm, PCOA is conducted until it has converged to a close neighborhood or it has reached its maximum iteration times, then the HSA is conducted for accurate solution. Different chaotic maps are compared and the impacts of parallel parameter on the hybrid algorithm are discussed.

The rest of this paper is organized as follows. Section 2 briefly describes chaotic maps. The PCOA approach is introduced in Section 3. Section 4 gives presentation of the proposed hybrid PCOA with HSA. Simulation results showing the effectiveness of the hybrid algorithm in Section 5. Conclusions are presented in Section 6.

2. Chaotic map

One dimensional noninvertible maps have capability to generate chaotic motion. In this study, eight well-known one-dimensional chaotic maps in [42] are considered here.

2.1. Logistic map

This map was introduced by Robert May in 1976, and he pointed out that the logistic map led to chaotic dynamics. Logistic map generates chaotic sequences in (0,1). This map is also frequently used in the COAs [2,14,22,34]. This map is formally defined by the following equation:

$$x_{n+1} = \varphi x_n(1 - x_n), \quad 0 < \varphi \le 4, \quad x_n \in (0, 1) \tag{1}$$

2.2. Tent map

Tent chaotic map is very similar to the logistic map, which displays specific chaotic effects. Tent map generates chaotic sequences in (0,1). This map is formally defined by the following equation:

$$\begin{aligned} x_{n+1} &= \frac{x_n}{0.7}, \quad x_n < 0.7 \\ x_{n+1} &= \left(\frac{10}{3}\right) x_n(1 - x_n), \quad else \end{aligned} \tag{2}$$

2.3. Chebyshev map

Chebyshev chaotic map is a common symmetrical region map. It is generally used in neural networks, digital communication and security problems [16]. Chebyshev map generates chaotic sequences in (−1,1). This map is formally defined [43]:

$$x_{n+1} = \cos(\varphi\, cos^{-1} x_n), \quad 0 < \varphi, \quad x_n \in [-1, 1] \tag{3}$$

2.4. Circle map

Circle chaotic map was proposed by Kolmogorov. This map describes a simplified model of the phase locked loop in electronics [44]. This map is formally defined [45]:

$$x_{n+1} = x_n + \vartheta - \left(\frac{\tau}{2\pi}\right)\sin(2\pi x_n)\, mod(1), \quad x_n \in (0, 1) \tag{4}$$

Circle map generates chaotic sequences in (0,1). In Eq. (4), x_{n+1} is computed mod 1.

2.5. Cubic map

Cubic map is one of the most commonly used maps in generating chaotic sequences in various applications like cryptography. This map is formally defined by:

$$x_{n+1} = \rho x_n(1 - x_n^2), \quad x_n \in (0, 1) \tag{5}$$

Cubic map generates chaotic sequences in (0,1) with $\rho = 2.59$.

2.6. Gauss map

Gauss map is also one of the very well known and commonly employed map in generating chaotic sequences in various applications like testing and image encryption. This map is formally defined by the following equation:

$$\begin{aligned} x_{n+1} &= 0, \quad x_n = 0 \\ x_{n+1} &= \frac{1}{x_n} mod(1), \quad x_n \neq 0 \end{aligned} \tag{6}$$

Gauss map generates chaotic sequences in (0,1).

2.7. ICMIC map

Iterative chaotic map with infinite collapses (ICMIC) [43] is formally defined by the following equation:

$$x_{n+1} = \sin\left(\frac{\alpha}{x_n}\right), \quad \alpha \in (0, \infty), \quad x_n \in (-1, 1) \tag{7}$$

ICMIC map generates chaotic sequences in (−1,1).

2.8. Sinusodial map

Sinusodial map is formally defined by the following equation:

$$x_{n+1} = \sin(\pi x_n), \quad x_n \in (0, 1) \tag{8}$$

Sinusodial map generates chaotic sequences in (0,1).

Typical behaviors of two chaos variables (x_1, x_2) based on different chaotic maps with 200 iterations are shown in Fig. 1. Here the initial points of two chaos variables are: $x_1 = 0.152$, $x_2 = 0.843$. Fig. 1(a) is the result of logistic map ($\varphi = 4$), Fig. 1(b) is the result of tent map, Fig. 1(c) is the result of Chebyshev map ($\varphi = 5$), Fig. 1(d) is the result of circle map ($\vartheta_1 = \vartheta_2 = 0.5$, $\tau_1 = \tau_2 = 5$), Fig. 1(e) is the result of cubic map, Fig. 1(f) is the result of Gauss map, Fig. 1(g) is the result of ICMIC map ($\alpha = 70$), Fig. 1(h) is the result of sinusodial map, respectively. From Fig. 1, it can be observed that each chaos variables are randomly distributed in their certain bounds. Although 200 iterations are shown, chaos variables have good ergodic properties with the increase of iteration times. This characteristic is very useful for global search, and it is helpful for COA's global optimum. From Fig. 1, it can also be observed that the distribution or ergodic property of different chaotic maps are different. Therefore, the search patterns of different chaotic maps differs with each others in view of convergence rate, algorithm speed and accuracy [14,42,44].

3. PCOA approach

In the PCOA proposed in our former study [34,35], multiple chaotic maps are mapped onto one optimization variable simultaneously, and the search result is the best value of parallel multiple chaotic maps. In this way, the PCOA method searches from several different initial points and detracts the sensitivity of initial condition.