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A self-adaptive harmony PSO search algorithm and its performance analysis

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ABSTRACT

Harmony Search (HS) algorithm is a new population-based meta-heuristic which imitates the music improvisation process and has been successfully applied to a variety of combination optimization problems. In this paper, a self-adaptive harmony particle swarm optimization search algorithm, named SHPSOS, is proposed to solve global continuous optimization problems. Firstly, an efficient initialization scheme based on the PSO algorithm is presented for improving the solution quality of the initial harmony memory (HM). Secondly, a new self-adaptive adjusting scheme for pitch adjusting rate (PAR) and distance bandwidth (BW), which can balance fast convergence and large diversity during the improvisation step, are designed. PAR is dynamically adapted by symmetrical sigmoid curve, and BW is dynamically adjusted by the median of the harmony vector at each generation. Meanwhile, a new effective improvisation scheme based on differential evolution and the best harmony (best individual) is developed to accelerate convergence performance and to improve solution accuracy. Besides, Gaussian mutation strategy is presented and embedded in the SHPSOS algorithm to reinforce the robustness and avoid premature convergence in the evolution process of candidates. Finally, the global convergence performance of the SHPSOS is analyzed with the Markov model to testify the stability of algorithm. Experimental results on thirty-two standard benchmark functions demonstrate that SHPSOS outperforms original HS and the other related algorithms in terms of the solution quality and the stability.

1. Introduction

In the real world production and engineering fields, many practical engineering problems can be transformed into optimization problems (Costantino, Di Gravio, Shaban, & Tronci, 2014;Kadambur & Kotecha, 2015; Xiao, Shao, Gao, & Luo, 2014). However, due to the traditional mathematical methods have certain limitations such as premature convergence, poor global search ability and require derivable fitness functions, so it is difficult to address complex optimization problems. After extensive research and exploration on optimization problems, researchers simulate a variety of evolutionary laws in nature, and many meta-heuristics are put forward. Classical meta-heuristics are described as follows, such as genetic algorithm (Chung, Chan, & Chan, 2013;Goldberg & Holland, 1988), simulated annealing (Arce, Román, Velásquez, & Parada, 2014;Kirkpatrick, 1984), particle swarm optimization (Eberhart & Kennedy, 1995;Leung, Tang, & Wong, 2012), ant colony (Xiao, Ao, & Tang, 2013), artificial bee colony (Gao & Liu, 2012), shuffled complex evolution (Zhao, Jiang, Zhang, & Wang, 2014a, 2014b, 2014c, 2014d, 2015) and other typical hybrid evolution computation algorithm (Zhao et al., 2014a, Zhao, Tang, Wang, and Jonrinaldi, 2014b, 2014c, 2014d; Zhao et al., 2014a, 2014b, Zhao, Tang, Wang, and Jonrinaldi, 2014c, 2014d; Zhao et al., 2014a, 2014b, 2014c, Zhao, Zhang, Wang, & Zhang, 2014d).

Harmony Search (HS) algorithm is a new meta-heuristic algorithm proposed by Geem, Kim, and Loganathan (2001), which is one of the effective methods for solving optimization problems. The basic idea of HS stems from the music improvisation, which mimics the process that musicians repeatedly adjust the pitches of different instruments so as to reach a pleasing harmony eventually. Compared with the earlier meta-heuristics, HS has many advantages such as simple concept, few parameters to be tuned and easy to implement, and also owns a particular way of exploring and exploiting the search space, which has made it very

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successfully in the optimization world, such as Dam system scheduling (Geem, 2007), Cluster analysis (Mehrdad Mahdavi & Abolhassani, 2009) and others (Li, Li, & Gupta, 2014;Salcedo-Sanz et al., 2013; Zou, Gao, Li, & Wu, 2011). However, the main drawback of the original HS is that the parameters are set to fixed values, and it is difficult to suggest values that work well in different situations. In order to enhance the accuracy and convergence performance of solution, a wide variety of modifications have been proposed.

Modifications of the HS mainly include two aspects: (1) by changing the way HS behaves (including HM initialization, parameters setting, the way of generating a new solution, algorithm structure and others); (2) by hybridizing HS with other meta-heuristic algorithms.

The parameters setting greatly affect the performance of HS, but tuning the parameters through experiments to obtain optimal setting is quite time-consuming. Therefore, a dynamic scheme is adopted by the researchers. Mahdavi, Fesanghary, and Damangir (2007) discussed the impacts of constant parameters on HS algorithm and then introduced dynamic parameters PAR and BW into HS, where PAR increased linearly and BW decreased exponentially with the number of generations. Experimental results show that performance of the IHS algorithm has been explicitly improved compared with original HS Omran and Mahdavi (2008) put forward global-best harmony search (GHS) inspired by PSO (Eberhart & Kennedy, 1995), which made full use of the direction information of the best harmony (best individual) in HM to guide the search. Experimental results show that the performance of GHS is superior to HS and IHS. Wang and Huang (2010) proposed a self-adaptive harmony search algorithm (SAHS) which excludes the selection of the values of parameters PAR and BW. That is, SAHS generated a new solution vector according to the maximum and minimum values of the decision variables in HM with some associated probability Pan, Suganthan, Tasgetiren, and Liang (2010) presented a self-adaptive global best harmony search (SGHS) algorithm inspired by GHS. Unlike GHS, SGHS employed a new improvisation scheme. HMCR and PAR are dynamically adapted by the learning mechanism. BW is dynamically tuned to favor exploration in the early stages and exploitation for the final stages Zou, Gao, Wu, Li, and Li (2010) developed a novel global harmony search (NGHS) algorithm inspired by the swarm intelligence of particle swarm. NGHS included two important mechanisms with a small probability, which are position updating and genetic mutation. The former enables the worst harmony in HM to move to the global best harmony rapidly, and the latter can effectively prevent the NGHS from trapping into the local optimum. Geem and Sim (2010) proposed a novel technique, named parameter-setting-free (PSF) Harmony Search algorithm, which eliminates tedious and experience-requiring parameter assigning efforts. PSF technique contains one additional matrix for each variable in harmony memory according to the certain operation type including random selection, memory consideration and pitch adjustment Pan, Suganthan, Liang, and Tasgetiren (2011) presented a local-best HS with dynamic sub-harmony memory, which randomly divided HM into sub-harmony memories. Sub-harmony memories recombine and exchange information each other after a certain generations. Meanwhile, a chaotic sequence to produce decision variables for harmony vectors and a mutation scheme are utilized to enhance the diversity of the HM. The kind of strategy can keep the algorithm diversity well. Chen, Pan, and Li (2012) proposed an effective HS which took advantage of tournament selection rule to generate a new harmony. PAR and BW are adjusted dynamically with respect to the evolution of the search process and the different search spaces of the optimization problems Ashrafi and Dariane (2013) presented an innovative improved version of HS, named Melody Search (MS) Algorithm. MS algorithm mimics performance processes of the group improvisation for finding the best succession of pitches within a melody. A novel Alternative Improvisation Procedure (AIP) was employed by Valian, Tavakoli, and Mohanna (2014) introduced a novel improvisation scheme, called an intelligent global Harmony Search, which employs the swarm intelligence technique Khalili, Kharrat, Salahshoor, and Sefat (2014) developed a global dynamic harmony search (GDHS) algorithm which eliminates setting parameters that have to be defined before optimization process. All the key parameters are changed to dynamic mode and there is no need to predefine any parameters. Kumar, Chhabra, and Kumar (2014) presented a parameter adaptive harmony search (PAHS) algorithm, where two key parameters HMCR and PAR are both being allowed to change dynamically. Four different cases of linear and exponential changes are explored in the PAHS algorithm. Castelli, Silva, Manzoni, and Vanneschi (2014) introduced a new variant of the Harmony Search algorithm, called Geometric Selective Harmony Search. A selection procedure was adopted in the improvisation phase. A recombination operator and a new mutation operator were employed in the memory consideration process. In short, different kinds of modifications (El-Abd, 2013;Hasan, Abu Doush, Al Maghayreh, Alkhateeb, & Hamdan, 2014; Mun & Cho, 2012;Wang et al., 2013; Yadav, Kumar, Panda, & Chang, 2012) emerge in endlessly.

The other aspect is hybridization with other meta-heuristics. The characteristics of two algorithms are extracted to improve the performance of HS. According to the strategy, Wang and Li (2012) put forward hybridization of DE/HS, where two populations evolve simultaneously and cooperatively, one population for the continuous part evolves by means of differential evolution while another population for the integer part evolves by means of Harmony Search. The DE/HS has been applied to address reliability–redundancy optimization problems. Wang and Guo (2013) presented HS/BA which betters the performance respectively. In the HS/BA, pitch adjustment operation in HS is served as a mutation operator during the process of the bat updating to speed up convergence. In order to accelerate search efficiency and performance, HS hybridized with PSO, called PSO-CE-GHS, was proposed by Wang and Yan (2013). In the PSO-CE-GHS, Harmony Search operators are applied to evolve the original population. PSO is applied to co-evolve the symbiotic population. Thus, the symbiotic population is dynamically and self-adaptively adjusted with the evolution of the original population Xiang, An, Li, He, and Zhang (2014) proposed an improved global-best harmony search (IGHS) algorithm. In IGHS, a new improvisation scheme based on differential evolution was employed to enhance the local search ability and a modified random consideration based on artificial bee colony algorithm for reducing randomness of the global-best harmony search (GHS) algorithm are integrated. HMCR and PAR are designed as a periodic function and a sign function in view of approximate periodicity of evolution in nature. Hosseini, Akbarpour Shirazi, and Karimi (2014) proposed a hybrid of Harmony Search (HS) and simulated annealing (SA) based heuristics for consolidation network. Moslehi and Khorasanian (2014) presented a hybrid variable neighborhood search (HVNS) algorithm hybridized with the simulated annealing algorithm, which is used to solve the flow shop problem. Literatures (Moh'd Alia & Mandava, 2011), (Manjarres et al., 2013) and (Yoo, Kim, & Geem, 2014) make a detailed survey on the development of HS, which are comprehensive references in recent years.

Although the performance of HS has been improved through the aforementioned methods, there are still some intrinsic problems in the original HS. Therefore, a self-adaptive harmony particle swarm optimization search algorithm, named SHPSOS, is proposed in this paper. Usually, PAR and BW are described either linear or exponential type. In SHPSOS, a new self-adaptive adjusting scheme for