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Pareto-based grouping discrete harmony search algorithm for multi-objective flexible job shop scheduling

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ABSTRACT

This paper proposes a Pareto-based grouping discrete harmony search algorithm (PGDHS) to solve the multi-objective flexible job shop scheduling problem (FJSP). Two objectives, namely the maximum completion time (makespan) and the mean of earliness and tardiness, are considered simultaneously. Firstly, two novel heuristics and several existing heuristics are employed to initialize the harmony memory. Secondly, multiple harmony generation strategies are proposed to improve the performance of harmony search algorithm. The operation sequence in a new harmony is produced based on the encoding method and the characteristics of FJSP. Thirdly, two local search methods based on critical path and due date are embedded to enhance the exploitation capability. Finally, extensive computational experiments are carried out using well-known benchmark instances. Three widely used performance measures, number of non-dominated solutions, diversification metric and quality metric, are employed to test the performance of PGDHS algorithm. Computational results and comparisons show the efficiency and effectiveness of the proposed PGDHS algorithm for solving multi-objective flexible job-shop scheduling problem.

1. Introduction

The flexible job-shop scheduling problem (FJSP) is a branch of the job-shop scheduling problem (JSP) with extensive practical applications [10,15]. The FJSP is an NP-hard problem [10,16]. The FJSP includes two sub-problems: (a) machine assignment that is to select a machine from a set of candidate machines for operations; and (b) operation sequence that is scheduling the operations on all machines to obtain a feasible solution. Thus, the FJSP is harder than the classical JSP. Generally, the objectives considered in FJSP include the maximal completion time (makespan), the total work load of machines, the maximal machine workload, the mean/total earliness time and tardiness time compared to the due date of jobs. Earliness and tardiness objectives are due date related criteria. The FJSP problem has wide application in manufacturing engineering, such as turning operations [42,43] and milling operations [44,45].

Brucker and Schile [2] developed a polynomial graphical algorithm for FJSP with two jobs known to be the first work for FJSP. Due to the complexity of FJSP, meta-heuristic algorithms have become the preferred solution techniques to produce

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good schedules in a reasonable time. Multi-objective FJSP has been studied by many researchers in recent years. Xia and Wu [39] proposed a hierarchical solution approach by using a particle swam optimization (PSO) algorithm to assign operations on machines and a simulated annealing (SA) algorithm to schedule operations on each machine. Gao et al. [6] employed a genetic algorithm which hybrids with a variable neighborhood descent algorithm for the multi-objective FJSP. Xing et al. [40] proposed a simulation model for solving multi-objective FJSP. This model is a general framework for the problem enabling the applications of different algorithms. Xing et al. [41] also employed a local search algorithm for the multi-objective total FJSP (T-FJSP) and partial FJSP (P-FJSP). The results show that the algorithms are efficient for FJSP problem, especially for the large scale FJSP problems. Zhang et al. [46] researched a hybrid PSO and tabu search (TS) algorithm to solve FJSP with multi-objective. Li [20] proposed a hybrid TS algorithm for multi-objective FJSP. In this research, a variable neighborhood search algorithm and a local search method are integrated. Additionally, Li [21] also employed a Pareto-domination based artificial bee colony (PDABC) algorithm for the multi-objective FJSP. An external Pareto archive set is designed in this paper to record the non-dominated solutions. And a fast non-dominated set update process is introduced in the algorithm. Wang [34] proposed an enhanced Pareto-based artificial bee colony (EPABC) algorithm for the multiple objectives FJSP. A local search strategy based on critical path is embedded in the search framework to enhance the local intensification capability. The results and comparisons show that the performance of EPABC is better than that of PDABC.

To solve the multi-objective FJSP, researchers primarily considered some combinations of the makespan, the maximal machine workload and total workload as objectives. A few researchers also considered due date related criteria: mean/total earliness time and tardiness time. Scrich et al. [32] considered the total tardiness in the FJSP and solved using a tabu search based algorithm. Wu and Weng [38] proposed a multi-agent method to optimize the earliness and tardiness objectives in FJSP. Gholami and Zandieh [13] minimized the makespan and mean tardiness objectives in a dynamic and flexible job shop. Vilcot and Billaut [33] optimized the makespan and maximum lateness objectives in a flexible job shop environment from printing and boarding industry. Fattahi [5] optimized the makespan and total weighted tardiness objectives.

Harmony search (HS) is a relatively recent meta-heuristic method developed by Geem et al. [11] for solving optimization problems. It imitates the music improvisation process of musicians. A harmony in music is regarded analogous to a solution vector in the corresponding optimization problem, while the musician's improvisations are regarded analogous to local and global search processes in optimization algorithms. The HS algorithm generates a new candidate solution by making use of all existing solutions. However, compared to other meta-heuristics, the HS algorithm imposes fewer mathematical requirements. Numerical comparisons also show that evolution in HS is faster than that of the GA [24,26].

In recent years, many researchers have developed improved HS algorithms and applied HS variants to solve scheduling problems [18]. Omran and Mahdavi [26] developed a global-best harmony search algorithm. Das [3] analyzed and improved the exploration power of HS algorithm. Geem applied HS algorithm for scheduling multiple water distribution systems [12]. Wang et al. [35] and Pan et al. [27] proposed a hybrid harmony search algorithm and a local-best harmony search algorithm with dynamic sub-harmony memories for solving blocking flow shop scheduling problem and lot-streaming flow shop scheduling problem. Gao et al. proposed a grouping harmony search algorithm [8] and a discrete harmony search (DHS) algorithm [7] for solving no-wait flow shop scheduling problem. Following the successful applications of HS algorithm, we proposed a Pareto-based DHS algorithm for flexible job shop scheduling problem [9]. This work developed a Pareto-based grouping discrete harmony search (PGDHS) algorithm to solve FJSP with makespan, the mean of earliness and tardiness criteria. In this paper, several existing heuristics were employed for initializing the harmony memory. A new heuristic was proposed for initializing harmony memory. A grouping strategy was used for improving the convergence. A new local search approach was proposed for minimization of earliness and tardiness. In addition, more benchmark instances were tested with detailed discussions and comparisons. Consequently, the performance of the proposed PGDHS algorithm is substantially improved beyond the conference paper [9]. The rest of this paper is organized as follows: In Section 2, we briefly describe the problem formulation of FJSP. The basic HS algorithm is introduced in Section 3. Section 4 presents the PGDHS algorithm in detail. Section 5 presents the experimental results and compares with other algorithms in existing literature to demonstrate the superior performance of the proposed PGDHS algorithm. Finally, we conclude the paper in Section 6.

2. Multi-objective flexible job shop problem

2.1. Multi-objective optimization

A multi-objective optimization problem can be described as follows:

$$\text{Min}\, f(x) = (f_1(x), f_2(x), \ldots, f_n(x)), \quad x \in \Omega, \quad f(x) \in R^n \tag{1}$$

where x is the decision vector in space Ω and $f(x)$ is the objective vector.

Pareto domination states that solution A dominates solution B if and only if $\forall i \in \{1, 2, \cdots, n\}, f_i(A) \leqslant f_i(B)$ and $\exists i \in \{1, 2, \cdots, n\}, f_i(A) < f_i(B)$. Solution A is an optimal in the Pareto sense if there is not any solution B which dominates A. Pareto optimal set is the collection of all Pareto optimal solutions and the corresponding image in the objective space is the Pareto front. In this paper, an archive set (AS) is used to record the non-dominated solutions during the iterations. During the search process, if one new solution dominates one or more solutions in AS, the new solution will replace the dominated solutions in AS.