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博　士　論　文　概　要

論　　文　　題　　目

Study on Quantum-Inspired Optimization Approaches for Flow Shop Scheduling Problems

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Flow Shop Scheduling Problem (FSSP) is generally considered to be one of the most critical issues in manufacturing industries of steel, semiconductor, textile, furniture, etc. However, with the development of modern manufacturing industries, the customers are demanding high-variety products, which have contributed to an increase in product complexity. Therefore, the effective scheduling system becomes more essential, which significant impacts on cost reduction, customer satisfaction, productivity increase and overall competitive advantage, especially in more complexity production cases. According to the requirement of modern manufacturing industries, this dissertation attempts to set up an effective scheduling system for FSSP.

Permutation FSSP and reentrant FSSP are two representative scheduling problems in flow shop production environment, which are most investigated in this dissertation. In the permutation FSSP, jobs are to be processed through a series of machines for optimizing number of required criteria. The permutation FSSP is proved to be NP-hard and even small size problems are difficult to solve. The reentrant FSSP is a more complex problem than permutation FSSP. It usually appears in the semiconductor industry, in which the routes of jobs on the machines are identical as in permutation FSSP, but the jobs must be processed by several machines in multiple times. Minimizing makespan (the time interval required to complete all the jobs) is one of the most essential criteria for the manufacturing industries to reduce cost and improve productivity. The first target of this dissertation is to minimize makespan for permutation FSSP. Furthermore, the highly competitive industries, such as food, beverage, semiconductor industry, also need on-time delivery to response the stress of competition on the markets. On-time delivery becomes other significant criterion. These factories desire a multi-objective scheduling system that simultaneously optimizes all the objectives to improve the competitiveness. To solve the multi-objective permutation FSSP and reentrant FSSP is the second target in this dissertation.

Up to now, many researchers have deal with the permutation FSSP using some heuristic methods to minimize makespan. However, based on the traditional methods it is hard to deliver an effective solution in a limited computation time, especially for large size problems. In recent years, numerously prospective researches have demonstrated that quantum computing is much efficient and fast for solving various complex problems on the quantum computer. Merging evolutionary computation and quantum computing, a new approach called Multi-update Mode Quantum Evolutionary Algorithm (MMQEA) has been proposed. MMQEA is innovated by q-bit individual and q-gate. The q-bit individual has a probabilistic representation of the solutions inspired by the superposition of q-bit. The q-gate with multi-update mode is used to renovate the quantum states of q-bit individual to evolve towards better solutions. The numerous experiments have verified that MMQEA have good global search ability, fast convergence behavior to address such problems.

To solve the multi-objective permutation FSSP, firstly, an effective multi-objective optimization algorithm called Parallel Quantum Evolutionary Algorithm (PQEA) has been developed based on the achievement of MMQEA. PQEA, a universal computation technique, is applicable for solving a variety of multi-objective optimization problems. The experimental results on benchmark problems has demonstrated that PQEA advances the most of famous multi-objective optimization approaches both in low computational cost and dominated solution attainment. Although PQEA has already archived better solutions on the multi-objective permutation FSSP, there is still some space to promote more. To further improve solution quality and accelerate convergence, Alternated Neighborhood Search (ANS) procedure is proposed. The neighborhood structures of ANS improve the convergence speed by utilizing the properties of permutation FSSP. Moreover, ANS controls search direction to exploit wider search space by the interaction of neighborhood structures.

In order to verify the practical applicability of developed approach, PQEA has been tested in a multi-objective reentrant FSSP of a real-world semiconductor factory. Due to the complexity of reentrant FSSP, the Quantum-to-Job (Q-to-J) method that transforms quantum states to real reentrant-job’s identifies is proposed. The results show that solutions obtained by PQEA have significantly improved both makespan and on-time delivery criteria, comparing with the previous used one in this factory.

Chapter 1 briefly introduces flow shop production environment, related approaches, our motivation, goals of this work and outline of the dissertation.

Chapter 2 MMQEA for permutation FSSP with makespan criterion

This chapter develops a novel evolutionary algorithm for permutation FSSP, called MMQEA, inspired by the concept of quantum computing. MMQEA is characterized by the representation of individual, evaluation function and population. However, instead of numeric or symbolic representation, MMQEA uses q-bit string to probabilistically represent the job sequences. A q-bit individual of MMQEA contains a pair of q-bit strings. There are two update modes that are proposed to update the quantum state of q-bit individual, in which each q-bit string relies on its corresponding update mode to renovate quantum state. Based on the two update modes, each q-bit string of the q-bit individual provides its evolutionary information to other one and also receives other one’s evolutionary information during the evolution, which maintains the population more diverse to exploit global optimal solution. For permutation FSSP with makespan criterion, MMQEA outperforms previous research with 3%, 6% and 7% improvement on 20×10 (20 jobs 10 machines), 50×10 and 50×20 problems.

Chapter 3 PQEA for multi-objective permutation FSSP

This chapter presents PQEA framework for multi-objective permutation FSSP with the criteria of minimizing makespan and maximum tardiness. To obtain an even distribution of solutions, firstly, PQEA decomposes uniformly this multi-objective problem into a number of scalar optimization sub-problems by decomposition method. All the sub-problems are classified into several groups according to their similarities. One q-bit individual is used to address the sub-problems of a group. Since q-bit individual is a probabilistic representation, it can share evolutionary information of the neighboring sub-problems in same group. Without loss any solutions of Pareto Front, a population of q-bit individuals are parallel evolved. Comparing with current state-of-the-art algorithms, PQEA outperforms all of them on dispersion performance, with 11.6%, 9.6%, 18.3% and 10.3% improvement for 20×20, 40×20, 60×20 and 80×20 problems.

Chapter 4 Hybridization of ANS for multi-objective permutation FSSP

This chapter develops ANS combining with multi-objective optimization approaches to further improve the convergence and dispersion performances. Firstly, utilizing the properties of active blocks for permutation FSSP, two neighborhood structures Multi-Objective Insertion (MOINS) and Multi-Objective Exchange (MOEXC) are designed in order to improve efficiency of perturbation. Any perturbation based on MOINS and MOEXC take positive effect on all objectives simultaneously, which can obviously improve convergence. ANS controls the search direction by systematically changing the neighborhood of MOINS and MOEXC to exploit more dominated solutions. The other advantage of ANS is no need to set parameters. Under the same computational times as terminal condition, numerous comparisons show that ANS has improved dispersion performance about 23%, 32%, 40%, and 46% on 20×20, 40×20, 60×20 and 80×20 problems.

Chapter 5 PQEA with Q-to-J method for multi-objective reentrant FSSP

In this chapter, the application of proposed algorithms in a real-world semiconductor factory is studied. For the real-world case investigated, jobs of various product types are to be processed on the flow line with reentry at critical resource stage (final testing) many times, which is a reentrant FSSP. This factory desires a scheduling system that to reduce makespan and penalty costs for tardiness job simultaneously. To apply PQEA on the reentrant FSSP, a transformation method Q-to-J that translates the quantum states to real job identities is proposed. By using the proposed scheduling approach, there are 8 schedules that obtained by PQEA are dominating the previous one. The makespan and penalty cost for tardiness are averagely reduced by 8% and 27%, respectively.

Chapter 6 concludes this work by reviewing the proposed scheduling approaches, which show a good performance for permutation and reentrant FSSP. Additionally, the potential topics for further research are discussed.