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Ensemble multi-objective biogeography-based optimization with application to automated warehouse scheduling

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ABSTRACT

This paper proposes an ensemble multi-objective biogeography-based optimization (EMBBO) algorithm, which is inspired by ensemble learning, to solve the automated warehouse scheduling problem. First, a real-world automated warehouse scheduling problem is formulated as a constrained multi-objective optimization problem. Then EMBBO is formulated as a combination of several multi-objective biogeography-based optimization (MBBO) algorithms, including vector evaluated biogeography-based optimization (VEBBO), non-dominated sorting biogeography-based optimization (NSBBO), and niched Pareto biogeography-based optimization (NPBBO). Performance is tested on a set of 10 unconstrained multi-objective benchmark functions and 10 constrained multi-objective benchmark functions from the 2009 Congress on Evolutionary Computation (CEC), and compared with single constituent MBBO and CEC competition algorithms. Results show that EMBBO is better than its constituent algorithms, and among the best CEC competition algorithms, for the benchmark functions studied in this paper. Finally, EMBBO is successfully applied to the automated warehouse scheduling problem, and the results show that EMBBO is a competitive algorithm for automated warehouse scheduling.

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1. Introduction

Warehousing is an important part of production supply chain management, and serves as the backbone in many manufacturing enterprises. Warehousing keeps stocks of products until they are ready to be delivered to the market place. A delay in product delivery may lead to the failure of production supply chains. Efficient warehouse management contributes to the timely delivery of the product (Choi et al., 2013; Yeung et al., 2010, 2011). Modern warehouses are equipped with storage and retrieval (S/R) machines to pick up products from an input/output (I/O) location and store them at specific locations, and then to retrieve outgoing products from other storage locations and deliver them to the I/O location. Although S/R machines enhance warehouse management, scheduling is a challenging and vital task (Lerher et al., 2015b; Wang and Fang, 2011). The time and cost of product allocation and delivery are important variables to consider during warehouse scheduling.

In the past few decades, warehouse scheduling has been the subject of much research, including energy efficient design (Lerher et al., 2013), travel time models for shuttle-based systems (Lerher et al., 2015a), travel time models for aisle transfer systems (Lerher et al., 2010a), travel time models for double-deep systems (Lerher et al., 2010b), and models for mini-load multi-shuttle systems (Lerher et al., 2011). Other automated warehouse schedule research is reported in Berg (1999), Chan and Kumar (2009), Roodbergen and Vis (2009), and Yang et al. (2013).

Warehouse scheduling is a typical NP-hard problem, which is one of the most challenging types of combinatorial optimization problems (Gagliardi et al., 2012). Since this problem is so important for production supply chain success, more research needs to be carried out to make automated warehouse scheduling more robust and efficient. Motivated by these considerations, this paper highlights the benefits associated with automated warehouse scheduling and introduces a new evolutionary algorithm to find efficient schedules for warehouse management.

In recent years, ensemble learning has been introduced to enhance the performance of various systems; for example, feature selection, optimization, clustering analysis, etc. Ensemble learning is a hybrid method that uses multiple learning models instead of a single model. This approach is intuitively attractive because a single model may not always be the best to solve a complex problem, but multiple models are likely to yield results that are better than each of the constituent models. Ensemble learning has been successfully applied to time series prediction and classification, and to

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evolutionary algorithms. It has been used with evolution strategies (ES) (Mallipeddi and Suganthan, 2010b), evolutionary programming (EP) (Mallipeddi and Suganthan, 2010a), harmony search (HS) (Pan et al., 2009), and differential evolution (DE) (Mallipeddi et al., 2011). It has been used to solve constrained optimization (Tasgetiren et al., 2010a), multi-objective optimization (Zhao and Suganthan, 2010), dynamic optimization (Yu and Suganthan, 2009), and the traveling salesman problem (Tasgetiren et al., 2010b).

Biogeography-based optimization (BBO) (Simon, 2008) is an evolutionary global optimization algorithm that was introduced in 2008. It is modeled after the immigration and emigration of species between habitats. The application of these processes to optimization allows information sharing between candidate solutions. BBO uses the fitness of each candidate solution to determine its immigration and emigration rate. The emigration rate is proportional to fitness and the immigration rate is inversely proportional to fitness. BBO has demonstrated good performance on various benchmark functions and real-world optimization problems (Ma and Simon, 2011). BBO has also been modified to solve multi-objective optimization problems (MOPs) (Chutima and Wong, 2014; Costa e Silva et al., 2012; Jamuna and Swarup, 2012; Ma et al., 2012).

The aim of this paper is to propose and study an ensemble of multi-objective biogeography-based optimization (MBBO) algorithms, including vector evaluated biogeography-based optimization (VEBBO), non-dominated sorting biogeography-based optimization (NSBBO), and niched Pareto biogeography-based optimization (NPBBO) (Simon, 2013), and apply the new algorithm to the automated warehouse scheduling problem. This paper shows how MBBO algorithms can be integrated to obtain a new algorithm called ensemble multi-objective biogeography-based optimization (EMBBO), and then presents a comparative study on multi-objective benchmark functions and automated warehouse scheduling problems. The methods in this paper could also serve as a template for the extension of any other evolutionary algorithm to multi-objective optimization.

The motivation of proposing EMBBO in this research is two-fold. First, we have observed that ensemble EAs outperform constituent EAs in many applications, as noted above, because of their greater adaptability. Second, we have observed that MBBO has proven itself to be an effective multi-objective optimization algorithm, also noted above. Combining these two observations leads us to propose an ensemble BBO algorithm, EMBBO, as a high-performing multi-objective optimization algorithm.

The original contributions of this paper include the following. (a) A new real-world-based automated warehouse scheduling model is formulated as a constrained multi-objective optimization problem. (b) The idea of ensemble learning is applied to MBBO to establish the new EMBBO algorithm. Results show that EMBBO outperforms its constituent MBBO algorithms for most of the unconstrained and constrained multi-objective benchmark functions that we study. (c) EMBBO has a lower computational cost than its constituent algorithms because it simultaneously uses multiple parallel populations to reduce running time in comparison with single MBBO algorithms which use populations whose number of individuals is the sum of the three constituent algorithms. (d) EMBBO solves the automated warehouse scheduling problem.

The remainder of this paper is organized as follows. Section 2 builds a mathematical model of the automated warehouse scheduling problem. Section 3 reviews the standard BBO and various MBBO algorithms, and then integrates them to realize EMBBO. Section 4 presents performance comparisons on benchmark functions between EMBBO, constituent MBBO algorithms, and 2009 Congress on Evolutionary Computation (CEC) algorithms, and then applies EMBBO to the automated warehouse scheduling model. Section 5 presents conclusions and suggests directions for future work. The abbreviations, notations, and symbols used in this paper are summarized in Appendix A.

2. Automated warehouse scheduling model

The layout of the automated warehouse system is shown in Fig. 1 (Yang et al., 2013), and is called a multi-aisle automated storage and retrieval system (multi-aisle AS/RS) with a curve-going S/R machine. It includes six components: S/R machine, picking aisles, cross warehouse aisle, storage racks (SR), rolling conveyor, and I/O location. As shown in the figure, the S/R machine can go in and out at both ends of every picking aisle, pick up products at the I/O location and store them at specific storage units in SR, and then retrieve outgoing products from other storage units and deliver them to the I/O location. The aim of an automated warehouse scheduling system is to improve scheduling efficiency.

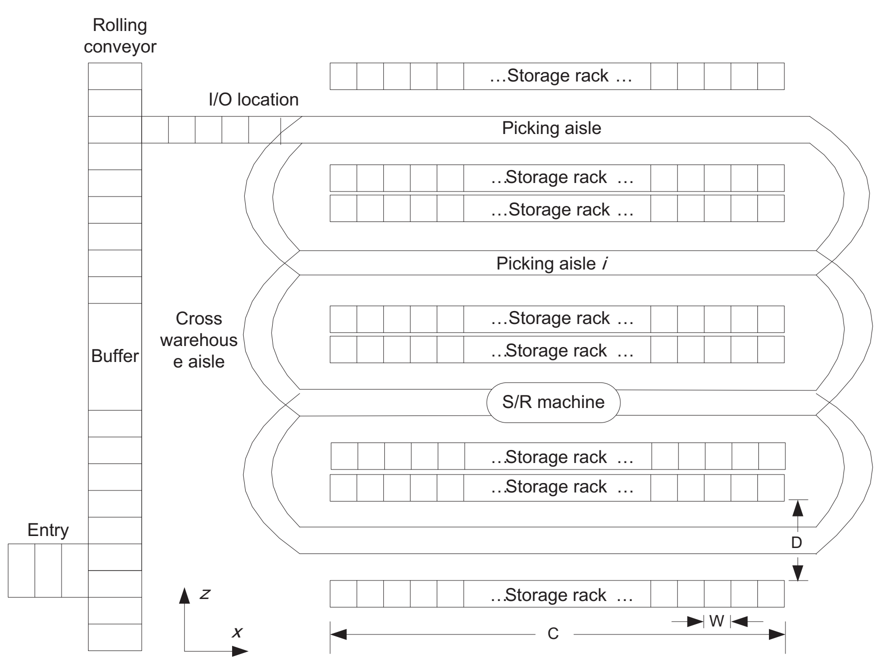

Fig. 1. Layout of the warehouse system.

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