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Bee colony intelligence in zone constrained two-sided assembly line balancing problem

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ABSTRACT

Bees Algorithm is a relatively new member of swarm intelligence based meta-heuristics which tries to model natural behavior of real honey bees in food foraging. Honey bees use several mechanisms like waggle dance to optimally locate food sources and to search new ones. This makes them a good candidate for developing new search algorithms for solving optimization problems in operational research. On the other hand, two-sided assembly lines are generally occurred in assembly of large-sized products such as buses and trucks. In a two-sided assembly line, different assembly tasks are carried out on the same product in parallel to both left and right sides of the line. In this study Bees Algorithm is adopted to solve two-sided assembly line balancing problem with zoning constraint so as to minimize the number of stations for a given cycle time. An extensive computational study is carried out and the results are compared with the results of several algorithms from the literature with the results of exact solution approaches and several algorithms from the literature such as ant colony optimization, tabu search.

1. Introduction

A branch of nature inspired algorithms which are called as swarm intelligence focused on insect behavior in order to develop some effective meta-heuristics which can mimic insect's problem solution abilities. Interaction between insects contributes to the collective intelligence of the social insect colonies. These communication systems between insects have been adapted to scientific problems for optimization. One of the examples of such interactive behavior is the waggle dance of bees during the food procurement. By the way of waggle dance, successful foragers share the information about the direction and distance to patches of flower and the amount of nectar within this flower with their hive mates. This is a successful mechanism in which foragers can recruit other bees in their colony to productive locations to collect various resources.

The information exchange among individual insects is the most important part of the collective knowledge. Communication among bees about the quality of food sources is achieved in the dancing area by performing waggle dance. The previous studies on dancing behavior of bees show that while performing the waggle dance, the direction of bees indicates the direction of the food source in relation to the sun, the intensity of the waggles indicates how far away it is and the duration of the dance indicates the amount of nectar on related food source. Waggle dancing bees that have been in the hive for an extended time, adjust the angles of their dances to accommodate the changing direction of the sun. Therefore bees that follow the waggle run of the dance are still correctly led to the food source even though its angle relative to the sun has changed. So collective intelligence of bees based on the synergistic information exchange during waggle dance. Observations and studies on honey bees' behaviors resulted in a new generation of optimization algorithms. Such an algorithm which is known as Bees Algorithm (BA) is used in this paper in order to solve two-sided assembly line balancing problem (two-sided ALB).

The paper is organized as follows; description of natural behaviour of bees and the literature survey on foraging behaviour of bees are presented in Section 2. In Section 3, two-sided ALB is clarified and in Section 4 the modified BA for two-sided ALB is explained in detail. Lastly, computational results and comparisons are presented in Section 5.

2. Behavior of bees in nature and literature survey

Social insect colonies can be considered as dynamical systems gathering information from the environment and adjusting their behavior in accordance with it. While gathering information and adjusting processes, individual insects do not perform all the tasks because of their specializations. Generally, all social insect colonies behave according to their own division of labors related to their morphology. As also presented in authors' previous work (Baykasoğlu, Özbakır, & Tapkan, 2007), Bee System consists of two essential components:

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2.1. Food sources

The value of a food source depends on different parameters such as its proximity to the nest, richness of energy and ease of extracting this energy.

2.2. Foragers

2.2.1. Unemployed foragers

If it is assumed that a bee has no knowledge about the food sources in the search field, bee initializes its search as an unemployed forager. There are two possibilities for an unemployed forager: (1) *Scout bee*: If the bee starts searching spontaneously without any knowledge, it will be a scout bee. The percentage of scout bees varies from 5% to 30% according to the information into the nest. The mean number of scouts averaged over conditions is about 10% (Seeley, 1995). (2) *Recruit*: If the unemployed forager attends to a waggle dance performed by some other bee, the bee will start searching by using the knowledge from waggle dance.

2.2.2. Employed foragers

When the recruit bee finds and exploits the food source, it will raise to be an employed forager who memorizes the location of the food source. After the employed foraging bee loads a portion of nectar from the food source, it returns to the hive and unloads the nectar into the food area in the hive. There are three possible options related to residual amount of nectar for the foraging bee. (1) If the nectar amount decreased to a low level or exhausted, foraging bee abandons the food source and become an unemployed bee. (2) If there are still sufficient amount of nectar in the food source, it can continue to forage without sharing the food source information with the nest mates. (3) Or it can go to the dance area to perform waggle dance for informing the nest mates about the same food source. The probability values for these options are highly related to the quality of the food source.

2.2.3. Experienced foragers

These types of foragers use their historical memories for the location and quality of food sources. It can be an inspector which controls the recent status of food source already discovered. It can be a reactivated forager by using the information from waggle dance. It tries to explore the same food source discovered by it if there are some other bees confirming the quality of same food source. It can be scout bee to search new patches if the whole food source is exhausted. It can be a recruit bee which is searching a new food source declared in dancing area by another employed bee.

The foraging behavior, learning, memorizing and information sharing characteristics of bees have recently been one of the most interesting research areas in swarm intelligence. Studies on honey bees are in an increasing trend in the literature during the last few years. An extensive literature survey and a classification of the previous algorithms on behavioral characteristics of the honey bees were presented by Baykasoğlu et al. (2007).

In this paper only ''foraging behavior'' based optimization algorithms are considered. Lucic and Teodorovic (2001, 2002, 2003a) and Lucic (2002) explored the possible applications of collective bee intelligence in solving complex traffic and transportation engineering problems. They proposed a Bee System (BS) algorithm which was applied to traditional traveling salesman problems. Lucic (2002), Lucic and Teodorovic (2003b) combined BS and fuzzy logic approach in order to obtain good solutions for stochastic vehicle routing problems. Teodorovic and Dell'Orco (2005) proposed a generalization of BS algorithm called Bee Colony Optimization (BCO) where the proposed algorithm is capable of solving deterministic combinatorial problems, as well as combinatorial problems characterized by uncertainty. Markovic, Teodorovic, and Acimovic-Raspopovic (2007) used the BCO algorithm to solve max-routing and wavelength assignment problem in all-optical networks. Nakrani and Tovey (2003) proposed a honey bee algorithm for dynamic allocation of internet services. Chong, Low, Sivakumar, and Gay (2006) presented a novel approach inspired by Nakrani and Tovey (2003), to solve the job shop scheduling problems. Wedde, Farooq, and Zhang (2004) introduced a bee behavior based routing protocol for routing in telecommunication network. Bianco (2004) presented a mapping paradigm for large scale precise navigation that takes inspiration from the bees' large scale navigation behavior. Drias, Sadeg, and Yahi (2005) introduced a new intelligent approach which is inspired from the behavior of real bees especially harvesting the nectar of the easiest sources of access while always privileging the richest. Quijano and Passino (2010) proposed an algorithm, based on the foraging behavior of honey bees to solve resource allocation problems. Baştürk and Karaboğa (2006), Karaboğa and Baştürk (2007), Yang (2005), Pham et al. (2006a) proposed different algorithms for solving continuous optimization problems based on foraging behavior of honey bees. The BA which was developed by Pham et al. (2006a) is a population-based search algorithm that mimics the food foraging behavior of swarms of honey bees. In its basic version, the algorithm performs a kind of neighborhood search combined with a random search and can be used for both combinatorial optimization and functional optimization. BA has been applied to several optimization problems by its initial developers, such as: training neural networks for pattern recognition (Pham, Otri, Ghanbarzadeh, & Koç, 2006b; Pham, Koç, Ghanbarzadeh, & Otri, 2006c; Pham et al., 2006d; Pham, Ghanbarzadeh, Koç, & Otri, 2006e; Pham et al., 2007a), forming manufacturing cells (Pham, Afify, & Koç, 2007b), scheduling jobs for a production machine (Pham, Koç, Lee, & Phrueksanant, 2007c), finding multiple feasible solutions to a preliminary design problem (Pham, Castellani, & Ghanbarzadeh, 2007d), data clustering (Pham, Otri, Afify, Mahmuddin, & Al-Jabbouli, 2007e), optimizing the design of mechanical components (Pham, Soroka, Koç, Ghanbarzadeh, & Otri, 2007f), multi-objective optimization (Pham & Ghanbarzadeh, 2007), tuning a fuzzy logic controller for a robot gymnast (Pham, Darwish, Eldukhri, & Otri, 2007g).

3. Problem definition

3.1. Assembly line balancing problem

The Assembly Line Balancing Problem (ALB) is to determine the allocation of the tasks to an ordered sequence of stations such that each task is assigned to exactly one station, no precedence constraint is violated, and some selected performance measure is optimized. The ALBs fall into an NP-Hard class of combinatorial optimization problems (Gutjahr & Nemhauser, 1964). Assembly lines can be categorized into one-sided and two-sided lines. A one-sided line is a line that uses only one side of the line, whereas a two-sided line uses both sides of the line in parallel. A one-sided assembly line is basic and simple form of line balancing problems having two main constraints: precedence relationship (no task is assigned to an earlier position than any of its predecessors), and cycle time (each task must be executed before the cycle time). Comprehensive literature reviews on existing techniques to solve ALB are studied by Ghosh and Gagnon (1989), Erel and Sarin (1998), Becker and Scholl (2006) and Scholl and Becker (2006).

3.2. Two-sided assembly line balancing problem

Two-sided assembly lines are generally occurred in assembly of large-sized products such as automobiles, buses and trucks. In a