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A co-evolutionary improved multi-ant colony optimization for ship multiple and branch pipe route design

Wen-Ying Jiang, Yan Lin*, Ming Chen, Yan-Yun Yu

Ship CAD Engineering Centre, Dalian University of Technology, Dalian 116024, PR China

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ABSTRACT

This paper presents a co-evolutionary improved multi-ant colony optimization (CIMACO) algorithm for ship multi and branch pipe route design. The purpose of CIMACO algorithm is to design appropriate pipe routes to connect the starting points and ending points in the layout space under various kinds of constraints. The ant colony optimization (ACO) algorithm is improved according to the characteristics of ship pipe routing which is used to solve the single pipe routing problem. Based on the improved ACO algorithm, the multi ant colony optimization (MACO) algorithm with co-evolution mechanism is used to solve the multi and branch pipe routing problem. In this paper, the pheromone direction information and pheromone extension process are developed in the proposed algorithm to improve the calculation performance. Compared with conventional method, CIMACO algorithm is better at avoiding the problem of local optimum and accelerating the convergence rate. Finally, the simulation results demonstrate the feasibility and efficiency of the proposed algorithm.

1. Introduction

Pipe route design (PRD) plays an important role in industry, especially in the ship design. The purpose of PRD is to figure out an optimal route from a start location to an ending location in an environment with obstacles under various kinds of constraints. PRD has been a hot research field all over the world since 1970s. The existing methods include maze running algorithm (Lee, 1961), escape algorithm (Hightower, 1969), network optimization (Nicholson, 1966), A⁎ algorithm (Zhu and Latombe, 1991), ant colony optimization (ACO) (Dorigo and Gambardella, 1997), particle swarm optimization (PSO) (Kennedy and Eberhart, 1995), genetic algorithm (GA) (Ito, 1999), expert system (Vakil and Zargham, 1988) and multi-agent (Fan et al., 2006).

Ship pipe route design (SPRD) is one of the most important steps in ship design since it can take over 50% of the total detail-design man-hours and all other detail designs depend on it (Park and Storch, 2002). It has not only general characters of PRD problem, but also its own individual characters. Some of intelligent methods have been used to solve SPRD problem. Wu et al. (1998) applied fuzzy functions and sequential coordination to optimization of machinery arrangement and pipe routing. Kang et al. (1999) described an expert system to get the pipelines automatically. Park and Storch (2002) proposed a cell-generation method to optimize pipelines in ship room. Roh et al. (2006) developed a pipe model using the generation method. Lu et al. (2008, 2010) developed several algorithms to solve the pipe-routing arrangements using free spaces models. Fan et al. (2006, 2007, 2009, 2010 proposed several methods to solve the SPRD problem. Liu and Lu (2009) used a 3D digital simulation environment to optimize the pipelines automatically. Zou et al. (2010) presented an orientation-location distribution algorithm to evaluate the spatial effect of pipe-routing. Liu and Wang (2008, 2012) presented a new branch pipe routing algorithm based on the Steiner tree theory. Wu et al. (2012) constructed an auto-routing ship ventilation system to build the round pipe components in the 3D environment. Asmara and Nienhuis (2006, 2007, 2008, 2013) developed the framework of pipe routing in process of the detailed ship design. Kim et al. (2013) developed an automatic pipe routing system in a shipbuilding CAD environment using network optimization. Kimura and Ikehira (2009, 2011) presented some methods for pipe arrangement. Many research results have been proposed so far.

In this paper, a CIMACO algorithm is present to solve the SPRD problem. ACO was first introduced by M. Dorigo to solve the combinatorial optimization problems. It has been proven powerful for optimization problems. Many research studies have been carried out to solve PRD problem using ACO algorithms (Fan et al., 2006, 2007). But ACO algorithms have the disadvantages of premature convergence and slow convergence rate. Hence, ACO algorithm is improved in some ways to overcome the defects in this paper, enhancing the performance of the proposed algorithm. The direction information is added in pheromone to improve the influence of the pheromone. The pheromone extension process is

* Corresponding author.

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introduced to expand influence extent of the pheromone. Based on the improved ACO algorithm, MACO algorithm is proposed to solve the problem of the multi and branch pipe routing in which the pipelines are represented by different populations. Furthermore, a co-evolution mechanism is embedded into the process of the MACO to strengthen the cooperation of populations.

The remaining part of this paper is organized as follows. Section 2 describes the process of the IACO algorithm for solving the problem of single pipe routing. Section 3 describes the process of CIMACO algorithm for solving the problems of multiple pipes and branch pipe routing. Section 4 shows the simulation results to demonstrate the feasibility and efficiency of the proposed algorithm. Finally, Section 4 contains the conclusion of this paper.

2. Improved ACO for single pipe routing

In this section, the improved ACO algorithm is presented to solve the problem of single pipe routing. ACO algorithm is improved according to the characteristics of SPRD. Compared with ACO algorithm, some steps in ACO algorithm are modified. The pheromone direction information and pheromone extension process are developed in the proposed algorithm to enhance computing performance. The flowchart of improved ACO algorithm is presented in Fig. 1.

2.1. Data structure

The purpose of PRD is to figure out an optimal route from a start location to an end location in an environment with obstacles under various kinds of constraints. In SPRD problem, the main constraints include (Fan et al., 2006): avoid obstacles; minimize the length of pipeline and the number of elbows; arrange pipes orthogonally and along walls if possible; consider the convenience of installation and frequent maintenance.

In SPRD problem, the search environment can be simplified to a cubic model space in the coordinate system. The space is meshed according to pipeline diameters and interval distance. The data structure is defined as follows and shown in Fig. 2.

$$path = \{vertex_1, vertex_2, \ldots, vertex_n\}$$
$$vertex = (x, y, z) \quad (1)$$

2.2. Search path

In ACO, ants move from node to node based on the probability which is involved with pheromone intensity and heuristic information. In this paper, a novel addressing method is proposed to accelerate the search process.

2.2.1. Select exploration direction

Ants select an exploration direction firstly when they want to move from current node to next node. The exploration direction is selected from the directions of three coordinate axes. In this paper, the direction information is added in the pheromone. When the current node is determined by the pheromone, its exploration direction is along to the direction of the pheromone. Otherwise, the exploration direction of the current is determined using the method of roulette selection.

The exploration direction of node j is defined as follows:

$$D_j = \begin{cases} D_{pt}^{\alpha 1} & \text{if } node_j \text{ is determined by } pt \text{ and } \alpha 1 = 1 \\ RS(X, Y, Z) & \text{otherwise} \end{cases} \quad (2)$$

D_{pt} represents the direction of the pheromone track. When node j is determined by the pheromone track, its exploration direction D_j is along to this pheromone track. $\alpha 1$ is the weight, which is defined as follows:

$$\alpha 1 = \begin{cases} 0 & \text{if } \quad q < q_0 \\ 1 & \text{otherwise} \end{cases}$$

$$q_0 = 0.6^{round(\tau_{pt}/60)} \quad (3)$$

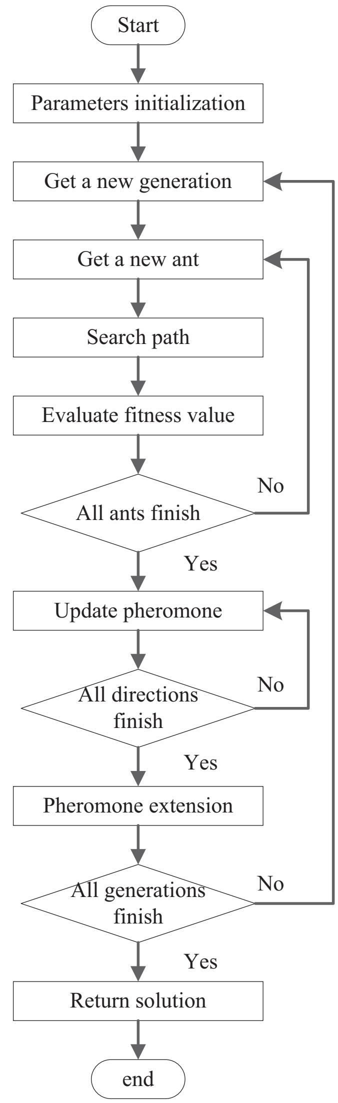

Fig. 1. Flowchart of IACO algorithm.

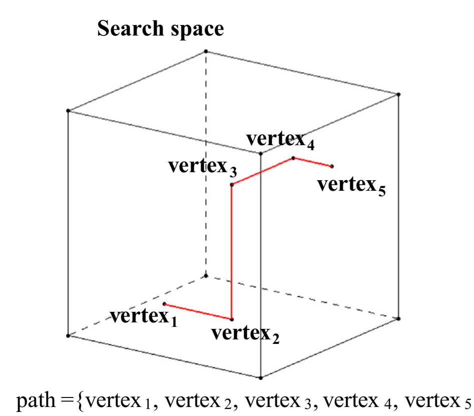

Fig. 2. Data Structure.