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A human-computer cooperation improved ant colony optimization for ship pipe route design

Yun-long Wang *, Yan-yun Yu, Kai Li, Xue-guo Zhao, Guan Guan

School of Naval Architecture, Dalian University of Technology, Dalian 116024, China

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ABSTRACT

This paper presents a human-computer cooperation improved ant colony optimization (HCCIACO) algorithm for ship pipe route design (SPRD). SPRD is a conbinatorial optimization problem with various performance constraints, it's hard to find an effective solution only by computer. Based on the human-computer cooperation theory, the HCCIACO algorithm takes full advantage of designers' expertise and experience as well as computers' calculation ability. It conbines the artificial sulotion and algorithm solution in the genetic sense of the improved ant colony optimization (IACO) algorithm so that the optimization approach for SPRD in three-dimensional space can be obtained. The improved ant colony optimization simplifies the problem by reducing the complexity in calculation and engineering to some extent. Meanwhile, it guides the algorithm to search effectively for the stable solution which satisfies the engineering requirements. In this paper, the structure and updating method of artificial solution as well as the combination mode of artificial solution and algorithm solution have been researched. Compare with the conventional mathod, HCCIACO algorithm not only improves the convergence speed, but also improves the quality of the solution. Finally, the simulation results demonstrate the feasibility and efficiency of the proposed algorithm.

1. Introduction

Pipe route design (PRD) is to figure out an optimal routes connecting the start location and the end location in an environment with obstacles under various kinds of constraints such as geometry, topology, technique, codes and regulations. PRD plays a significant role in industry especially in ship design. The research of PRD has developed from simple constraints in two dimensions to multi-objective constraints in three-dimensional space Since 1970s. The conventional methods include maze running algorithm (Lee, 1961), network optimization (Nicholson, 1966), escape algorithm (Hightower, 1969), network optimization algorithm (Wangdahl et al., 1974), dynamic programming method (Van Der Tak and Koopmans, 1976), Zhu algorithm (Zhu and Latombe, 1991), expert system (Vakil and Zargham, 1988), fuzzy set theory (Wu et al., 1998), genetic algorithm (Ito, 1999), ant colony algorithm (ACO) (Fan et al., 2006). These researches are very useful and valuable to the further research of PRD. However, there was no set of mature theory and ideal method until now because of the various layout environment and complicated constraints.

PRD is one of the main contents of the ship design. The good ship pipe route design is very important for the safety, economy, maneuverability, maintenance, rationality of overall layout, safe navigation and guaranteeing the normal operation of all kinds of machinery. SPRD has always been the hot and difficult issues in ship design. Some intelligent algorithms have been used to solve it. Kang et al. (1999) introduced a design expert system for auto routing of ship pipes. Fan et al.,(2007a, b) adopted a variable length coding genetic algorithm suitable for SPRD in 3D space. Jiang et al. (2014) used the improved ant colony genetic algorithm to solve the problem of ship single pipe routing optimization. Fan et al., 2006 introduced the ant colony algorithm into ship piping layout optimization design. Qu and Jiang (2011) proposed a dynamic ant colony algorithm, and established dynamic heuristic information with modeling space and ant location change. Feng et al. (2010) developed an automatic pipe routing algorithm based on the analysis of thermal interference. Liu et al, (2009) introduced the method of pipeline layout based on particle swarm algorithm and designed a particle coding mechanism based on the grid. Fan et al. (2009, 2007a,b) combined the ant colony algorithm with the cooperative algorithm to construct a multi-ant colony cooperative co-evolutionary algorithm model for the parallel laying of ship pipes, which can achieve better routing results in pipe parallel laying. Wu et al. (2008) optimized the layout of ship branch pipes with co-evolutionary ant colony algorithm. Jiang et al. (2015) presented a co-evolutionary

* Corresponding author.
E-mail address: yunlongw@dlut.edu.cn (Y.-l. Wang).

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improved multi-ant colony optimization algorithm for ship multi and branch pipe route design.

Both theories man-machine synergy brought by Lenat and Feigenbaum (1988)and human-computer cooperation introduced by Qian et al. (1990) delivered an idea that the collaborative relationship was existed between computer and human. By completing the tasks which human and computer were good at respectively, a final collaborative outcome was obtained. This idea re-evaluated the contribution of human intelligence and machine intelligence, and changed the technical route from being MI-centered. Since then, many scholars studied the mathod of human-computer cooperation, achieved a lot of results. Woods et al. (1990), Jones (1995), Lucas et al. (2010) researched the human-machine systems. Dai (1994) given a systematic description on the point of view of man-computer cooperation and the idea of metasyntactic wisdom of man-computer cooperation. Dai (1994) built a giant man-computer cooperated intelligent system for dealing with complex problem. Zhang et al. (2012), Huo et al. (2010) and Liu and Teng (2008) used the method of human-computer cooperation for satellite module layout optimization design, and achieved good results.

From the research production achieved for PRD optimization, we can find most researches were focused on algorithm itself. In this case, designers' expertise and experience are not fully utilized, and the process of PRD optimization lacks of effective guiding means. It is difficult to obtain the stable solution wich can meet engineering requirements. At present, two key problems need to be solved for SPRD: one is how to construct the effective algorithm; the other is how to make full use of the knowledge and experience of piping design experts.

In this paper, a HCCIACO algorithm is presented to solve SPRD problem in 3D space. Human-computer cooperation theory is considered throughout the whole solving procedure. This paper has researched the combinatorial mechanism of artificial solution and algorithm solution, and the construction and updating rules of artificial solution. ACO algorithm is improved in some ways to overcome the defects of premature convergence and slow convergence rate in this paper, enhancing the performance of the proposed algorithm. The direction guidance mechanism is established to further improve the convergence speed. With an effective collaborative relationship built between the artificial solution (artificial individuals) and algorithm solution (algorithm individuals), environment model related and SPRD optimization model based on human-computer cooperation are built. Further, the HCCIACO algorithm can be obtained.

This paper is organized as follows: Section 2 introduces the key technique of SPRD optimization approach based on human-computer cooperation; Section 3 introduces SPRD optimization model; Section 4 describes the process of HCCIACO algorithm for solving the problems of SPRD; Section 5 shows the simulation results to demonstrate the feasibility and efficiency of the proposed algorithm; Section 6 discusses the addition principles of artificial individuals; Finally, Section 7 contains the conclusion of this paper and the further research.

2. Key technique of SPRD optimization approach based on human-computer cooperation

2.1. Access to artificial individuals

In order to achieve effective human-computer cooperation in SPRD, various kinds of aspects should be considered. The fundamental approach is to realize gene fusion and information interaction between artificial solution and algorithm solution. Therefore, the first step is to acquire artificial individuals. There are three major means to obtain artificial individuals as follows:

(1) Self-designed method: To a specific SPRD optimization problem, designers, normally experienced pipe experts and engineers, design artificial individual themselves taking engineering practice and calculation environment into full consideration, and meanwhile, thinking about the coding system of algorithm individual with their expertise and long-term design experience accumulated. The advantage of it is that the design solution combines with good property of algorithm individual and complies with various kinds of constraint conditions of layout environment with great feasibility. However, it has low automation and requires high standard for designers. When it comes to the complicated optimization design in 3D, this method can consume a lot of time and require loads of design work.

(2) Preferential method: To different pipe route optimization design, designers selected the best algorithm individual from pure algorithm optimization solutions as artificial individual for engineering practice and calculation environment based on their expertise and experience. This method saves a lot of time and energy. But because of low participation rate of designers in the production of artificial individual, designers' expertise and experience are not fully utilized, which may lead to the lack of fine genes in artificial individual. Besides, this method has a high standard for algorithm related, which greatly increases the difficulty of algorithm design process.

(3) Modification method: Aiming at the optimal design of a specific pipeline, designers selected pure algorithm optimization solution with proper modification as artificial individual for engineering practice and calculation environment based on their expertise and experience. This method fully considers the designers' experience and maintains high efficacy. Meanwhile, good human-computer cooperation is guaranteed by adding good genes to artificial individual which algorithm individual don't possess.

2.2. Artificial individual reference set construction

Artificial individual reference set (AIRS) consists of experience and achievement of pipe experts and engineers as well as individual updating rules in the process of algorithm iteration. The individual updating rules is pre-designed in the procedure and is consistent during iteration. Pipe experts and engineers can participate during iteration and inspect efficacy of algorithm. To maintain diversity in AIRS, index M_std for evaluating diversity of reference set is adopted. To begin with, M_std should be calculated. When AIRS is updating, difference values between new artificial individual and original artificial individuals should be calculated. Compare the minimum difference value M_min with M_std. If M_min > M_std, put new artificial individual into reference set. Otherwise, the information will be delivered to designers. Designers can make changes on new artificial individual to satisfy the requirement or redesign a new artificial individual. The flowchart of AIRS is presented in Fig. 1.

Diversity difference value M_min (A, B) between artificial individual A and B in reference set can be denoted by Euclindean distance as follows:

$$M\_\min(A,B)=\sqrt{\sum_{i=1}^{n}(A_i-B_i)^2}\quad \forall i=1,2,\ldots,\mathrm{n} \tag{1}$$

2.3. Combination methods between artificial individual and algorithm individual

Pipe design engineers give artificial individual through numerical design plan of SPR and add it to AIRS. Pure algorithm solution that fulfills requirements related can also be put into AIRS. Based on the above, AIRS is developed to diversity scheme reference set (DSRS) so as to obtain artificial individuals of better combination with algorithm individuals. Artificial individuals of AIRS and DSRS are coded to form a unified numerical code pool with a specific coding mode. Their fitness value and diversity value decide whether they can be added into evolutionary