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Research on Thrust Distribution of Ship Dynamic Positioning System based on Hybrid Frog Leaping Algorithm

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Abstract

Aiming at a class of nonlinear constrained thrust allocation problem in ship dynamic positioning system, a hybrid frog leaping algorithm is proposed to solve the multivariable nonlinear constrained optimization problem, which takes the minimum energy consumption of propulsion system as the objective and the thrust, azimuth range and change rate as the constraints. The simulation results show that the algorithm can solve the thrust distribution optimization problem, and can take into account the energy consumption and maneuverability of the ship propulsion system, and effectively improve the performance of the ship dynamic positioning system.

Keywords

Dynamic Positioning System; Hybrid Frog Leaping Algorithm; Thrust Distribution.

1. Introduction

In order to overcome the limitation of traditional mooring application, most ships are equipped with dynamic positioning system. This system relies on the thrust generated by the ship's own propulsion system to offset the interference of the external environment, so as to keep the ship in a certain position and heading, so as to ensure its normal running or operation. Propulsion system is the actuator of dynamic positioning system, which plays an important role. The thrust distribution problem is the process that the propulsion system allocates the thrust and thrust angle to each propeller in real time, that is, the ship propulsion system allocates the command of the control system to each propeller of the propulsion system reasonably and efficiently through the thrust distribution unit according to the control command given by the control system, so as to determine the thrust and azimuth angle of each propeller[1-5].

2. Improved shuffled frog leaping algorithm

2.1 Hybrid frog leaping algorithm

In general, the hybrid frog leaping algorithm can be described as follows: in a limited space pond, the initial frog population is randomly generated at the beginning[6], the whole population is composed of a certain number of frogs of the same type, and the individuals in the frog population are irregularly distributed and include the whole pond (solution space) In the pond of space, individuals jump and forage frogs through information sharing[7]. To sum up, the composition of hybrid frog leaping algorithm can be summarized as the interaction of individuals with cultural genes in the population, and the individual population evolves according to certain rules and the information sharing mechanism between groups. The basic concepts of hybrid leapfrog algorithm include frog, population, subpopulation, fitness value, local search, subpopulation mixing, initial parameters and iteration termination conditions. In the above concepts, local search and subpopulation mixing are the direct performance of local search ability and global search ability of hybrid leapfrog algorithm, and will

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affect the optimization results. The specific concepts are as follows: Frog: the individual that constitutes the whole population, which is also the carrier of individual and global information sharing; population: at the beginning of the hybrid frog leaping algorithm, a group of groups generated according to certain rules or random, the initial stage of the population The initial value is very important, which will affect the iterative convergence speed and optimization results; subpopulation: after the initial population is generated, the initial population is divided into several subpopulations with the same number according to certain criteria, and each subpopulation has an independent idea in the search process; fitness value: each frog in the whole frog population has this value, and the individual's quality can be judged by this value; Local search: the sub population carries out local search according to the specific search strategy, so that the information on the carrier can be transferred and exchanged among local individuals; sub population mixing: after the local search, the sub population is mixed to exchange information among the whole population in order to maintain the diversity and global search of the population; Initial parameters: the hybrid frog leaping algorithm needs to set some necessary parameters before calculation, such as the population size, the number of subpopulations, the maximum allowable frog step size, the number of local iterations, and the global maximum number of iterations

2.2 Improved shuffled frog leaping algorithm

In the previous section, the principle and model of the hybrid frog leaping algorithm are introduced. Although the hybrid frog leaping algorithm has the advantages of simple mechanism, strong robustness and fast solution speed, it is still inevitable that the common shortcomings of intelligent algorithms are slow convergence speed, low optimization accuracy and easy to fall into local optimization. This chapter improves the shortcomings of the basic hybrid frog leaping algorithm in the evolution process: using the opposition strategy to initialize the population, improve the quality of the initial population, so as to improve the convergence speed; using an adaptive factor to dynamically adjust the update step of the worst individual; proposing a multidimensional greedy search algorithm to update the optimal individual of the population, so as to improve the convergence speed The optimization precision of the population. Do not In the optimization process of hybrid frog leaping algorithm, the local worst individual update step is very important for the global search ability. The value of update step size will directly affect the moving step size, which will affect the convergence speed and optimization accuracy. In order to improve the iterative speed and search accuracy of the algorithm, an adaptive step size updating strategy is applied. Through the research of the hybrid frog leaping algorithm, it is found that in the early stage of the search, if the step value is small, the search range will be large, so that the algorithm can accurately reach the target area; if in the middle and late stage of the search, if the step value is large, it can enhance the global search ability and make the solution jump out of the local optimum.

Local update strategy:

$$\begin{cases} D(t+1) = rand()*(X_b - X_w) \\ X_w(t+1) = X_w(t) + D(t+1) \end{cases} \tag{1}$$

3. Mathematical model of ship dynamic positioning

3.1 Ship kinematics

For the ship in the horizontal plane with only three degrees of freedom of pitch, roll and head roll[9], the kinematic equation can be expressed as follows:

$$\eta = [x, y, \psi]^T \tag{2}$$

In the formula, $\eta = [x, y, \psi]^T$ Is the position coordinate vector in inertial coordinate system, The expression of rotation matrix is as follows:

$$R(\psi) = \begin{bmatrix} cos\,\psi & -sin\,\psi & 0 \\ sin\,\psi & cos\,\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

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3.2 Ship dynamics

When the dynamic positioning ship sails at low speed on the horizontal plane, it changes slowly. Therefore, the influence of Coriolis centripetal matrix on the ship motion and the nonlinear damping matrix are ignored, and a simplified ship low frequency motion model is obtained.

$$Mv + \mathrm{D}v = \tau + R^T(\psi)b \tag{4}$$

4. Thrust distribution problem

4.1 Mathematical description of thrust distribution

The principle of thrust distribution in ship dynamic positioning system is introduced. By analyzing the principle of thrust distribution, it is known that the problem is a multi-objective optimization problem with constraints. Then, the main device of ship propulsion system, propeller, is described, and the operation characteristics of the propeller are analyzed, including the power consumption and mutual interference of the propeller. Finally, according to the principle of thrust distribution and the characteristics of propeller, the thrust distribution model of ship dynamic positioning system is established. The model is mainly divided into two parts: the objective function and the constraint conditions. The objective function term mainly considers the propeller power consumption, the thrust error penalty term, the propeller wear penalty term, and the balance term of ship maneuverability. The constraint term of thrust allocation includes the balance constraint of thrust, the working range of thrust and thrust angle, the thrust and thrust angle Thrust angle rate constraint. Therefore, the nonlinear constrained multi-objective ship dynamic positioning thrust allocation problem has been modeled. The thrust allocation optimization model not only provides the basis for the subsequent research of thrust allocation algorithm. The ship thrust distribution problem can be regarded as a nonlinear optimization problem with multi variables and constraints. By establishing appropriate objective function and constraints, the energy consumption of propulsion system, thrust error between control system and propulsion system, propeller wear and other factors can be minimized to ensure the maneuverability of the ship, and the command of control system can be distributed to each propeller The thrust and azimuth of each propeller are determined. The main function of the thrust distribution unit is to receive the force and torque commands from the control system, and determine the thrust and thrust angle of each propeller through a certain method.

$$\tau = B(\alpha)U \tag{5}$$

$$B(\alpha) = \begin{bmatrix} cos(\alpha_1) & \cdots & cos(\alpha_i) \\ sin(\alpha_1) & \cdots & sin(\alpha_i) \\ lx1\, sin(\alpha_1) - ly1\, cos(\alpha_1) & \cdots & lxi\, sin(\alpha_i) - lyi\, cos(\alpha_i) \end{bmatrix} \tag{6}$$

The thrust distribution principle of dynamic positioning system is shown in the figure below

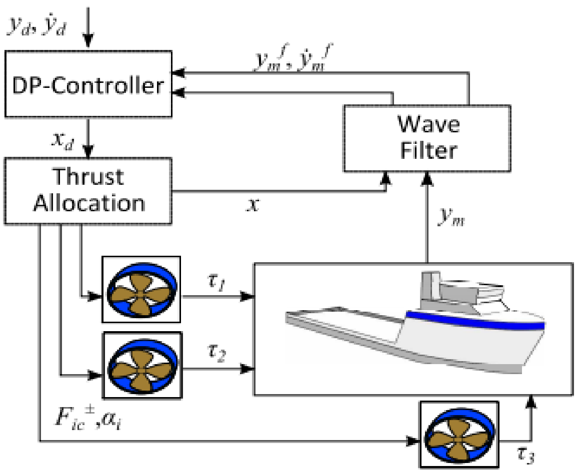

Fig. 1 Thrust distribution diagram of dynamic positioning system

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4.2 Objective function and constraints of thrust distribution

The constraints of ship thrust distribution mainly consider two aspects, that is, the limitation of propeller characteristics and thrust balance. Thrust balance constraint actually means that the error between the expected control force and torque given by the control system and the propulsion force and torque produced by the propulsion system should be as small as possible, so as to ensure that the ship can travel or operate according to the expected trajectory. Another constraint that needs to be considered is the change rate of thrust and thrust angle[9]. For fixed azimuth thrusters, only the change rate of thrust should be considered. For all rotary thrusters, the change rate of thrust angle should also be considered. In addition to the force balance equation, the constraint conditions of thrust distribution problem also need to consider the performance constraints of thruster, such as the extremum of thrust and azimuth, and the range of thrust and azimuth[10]. There are the following constraint expressions:

$$\begin{cases} \text{Umin} \le \text{U} \le \text{Umax} \\ \Delta U \min \le U - Uo \le \Delta \text{U} \max \\ \alpha \min \le \alpha \le \alpha \max \\ \Delta\alpha \min \le \alpha - \alpha o \le \Delta\alpha \max \end{cases} \tag{7}$$

5. Conclusion

Aiming at the problem of thrust distribution optimization in dynamic positioning system, a thrust distribution strategy based on hybrid frog leaping algorithm is designed by introducing and improving hybrid frog leaping algorithm. Through the simulation of the ship, it is proved that the algorithm can solve the problem of thrust distribution optimization. The algorithm can effectively reduce the wear of the propeller while considering the energy consumption. Because the angle of the propeller is not completely consistent at the same time, it can effectively solve the problem of the singular structure of the propeller system and improve the dynamic performance of the ship.

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