# Thrust distribution algorithm based on supervision and switching and swarm intelligence

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**Abstract.** The ship power positioning control system is the key to maintain the normal operation of the ship, and it is also the basic premise and foundation for the accurate positioning and stable forward movement of the ship, so many ship management and production enterprises attach great importance to the design and construction of the ship power positioning control system. "Thrust distribution" has always been the key technology for designing and constructing ship power positioning control system. When constructing ship power positioning control system by using thrust distribution technology, it is not only necessary to consider the constraint optimization of thrust limit and thrust rate of change limit of propeller, but also the constraint optimization of azimuth rate of change limit, mechanical wear optimization, restricted area limit optimization, etc. It is also necessary to consider the constraint optimization of azimuth rate of change limit, mechanical wear and tear, restricted area limit, etc. The thrust distribution algorithm based on supervision and switching and group intelligence can comprehensively deal with these constraints, which can improve the functions of the ship power positioning control system and solve the convergence problem in the system operation, and improve the operation efficiency, safety and stability of the ship power positioning control system. In this paper, the author discusses the thrust distribution algorithm based on supervision and switching and group intelligence in depth, combining relevant literature and the actual problem of thrust distribution.

**Keywords:** ship power positioning control system; group intelligence; supervision and switching; thrust distribution algorithm; optimization analysis.

## 1. Introduction

Since the reform and opening up, all the major industries in China have entered into high speed development, including the marine industry, and many advanced ship driving technologies have been derived to improve the safety of ship travel. Some literature shows that "the power positioning system, especially the ship power positioning control system, has become an indispensable system for marine engineering ships and belongs to a kind of drive system." Usually, the drive system is required for power positioning ships, which is essentially to allocate the combined force command of system requirements to each thruster reasonably, and then these thrusters distribute the thrust to achieve power positioning and drive the ship safely [1].

The "constrained optimization problem" is the main thrust distribution problem of the ship power positioning control system, which needs to meet the combined force demand and the physical conditions of the thrusters at the same time, so the ship power positioning control system is prone to the problems of high power consumption and mechanical wear and tear in operation. Therefore, the thrust distribution algorithm based on supervision and switching and group intelligence can effectively solve the above problems, so the following section firstly outlines the current situation of ship power positioning control system and thrust distribution research, then analyzes the mathematical model of ship power positioning thrust distribution, and proposes the "two-way exhaustive" mixed group algorithm (a thrust distribution optimization algorithm based on group intelligence). Finally, it analyzes the optimal thrust distribution based on supervision and switching and group intelligence.

Aiming at the various thrust distribution problems (large power consumption, large mechanical wear, etc.) appearing in the ship power positioning control system, many researchers at home and abroad have conducted in-depth research on this and achieved great success, effectively breaking

through the azimuth change rate limit, mechanical wear limit, forbidden area limit thruster thrust limit and thrust change rate limit of the system, so as to reduce the large power consumption, large mechanical wear and other problems incidence [2]. For example, Winchers et al. optimized the ship power positioning control system with the help of thruster grouping method, which can effectively solve the thrust distribution problem; Morgan et al. used the distribution logic method to solve the thrust distribution problem (also known as the column quadratic programming method); Johansen et al. proposed "the use of supervised and switching and group intelligence to optimize the inference algorithm, and then on the This basis optimizes the ship power positioning control system so as to achieve an effective solution to the thrust distribution problem." Li Xinfei et al. combined the pseudo-inverse method and the control volume normalization method to optimize the original thrust distribution algorithm, and then built the ship power positioning control system based on this algorithm to solve both the thrust distribution problem and the saturation problem and the thrust loss problem existing in the direct use of the pseudo-inverse method; Yang Shiqi et al. proposed that "the thrust distribution problem can be solved by setting the thrust distribution exclusion zone, and the thrust distribution problem can also be solved by The thrust distribution problem can be solved by setting the thrust distribution exclusion zone, and the ship power positioning control system can be optimized by the group intelligence based optimized thrust distribution algorithm, so as to reduce the incidence of various thrust distribution problems caused by the system operation safety and stability." Shi Xiaocheng et al. proposed that "the thrust distribution problem can be solved by combining biased thrust distribution algorithms." Although the methods proposed by the above researchers have alleviated the thrust allocation problem to a certain extent, there are still many shortcomings in the comprehensive consideration of thrust allocation constraints and optimization conditions, while the thrust allocation algorithm based on supervision and switching and swarm intelligence can effectively compensate for these shortcomings and effectively solve complex optimization problems with multiple constraints, nonlinearities, and multiple dimensions [2-3].

## 2. Thrust allocation problem constraints and mathematical model

Thrust distribution is the core of the power positioning ship control system, and the optimization goal of thrust distribution is not only to improve the output desired torque and control force of the controller, but also to reduce energy loss and mechanical wear and tear, so the thrust distribution must be continuously optimized [3]. Thrust distribution problem constraints and mathematical model is the key to optimize the thrust distribution, where the constraints include desired control force constraints, moment constraints, thruster constraints, etc.; the mathematical model is a mathematical model of the thrust distribution problem constructed according to the thrust distribution objectives and constraints, as follows.

$$\begin{cases} J(\alpha, f, S) = \sum_{i=1}^{n} \omega_i \left| f_i \right|^{3/2} + S^T Q S + \Delta\alpha^T \Delta\alpha + \dfrac{\delta}{\varepsilon + \det(B(\alpha) B^T(\alpha))} \\ S = \tau_c - B(\alpha) f \\ f_{\min} \le f \le f_{\max} \\ \Delta f_{\min} \le \Delta f \le \Delta f_{\max} \\ \alpha_{\min} \ge \alpha \le \alpha_{\max} \\ \Delta\alpha_{\min} \le \Delta\alpha \le \Delta\alpha_{\max} \end{cases} \tag{1}$$

$$B(\alpha) = \begin{vmatrix} \cos(\alpha_1) \cdots \cos(\alpha_n) \\ \sin(\alpha_1) \cdots \sin(\alpha_n) \\ -l_{y1} \cos(\alpha 1) + l_{x1} \sin(\alpha_1) \cdots - l_{yn} \cos(\alpha_n) + l_{xn} \sin(\alpha_n) \end{vmatrix} \tag{2}$$

Equation 1 in.

$f \in \Re^n$ -- each thruster thrust.

$\alpha \in \Re^n$ --the azimuth of each thruster.

$B(\alpha)$ --thruster position construction matrix.

$S$ --relaxation variables (to ensure that the thrust distribution problem always has a feasible solution).

In Equation 2.

$(l_{xn}, l_{yn})$ -- the position of the nth thruster in the hull coordinate system.

$\alpha_n$ --the azimuth of the nth thruster.

## 3. "Two-way exhaustive" mixed swarm algorithm (group intelligence optimization algorithm)

### 3.1. Principle of algorithm formation

The "two-way exhaustive" mixed swarm algorithm belongs to the group intelligence optimization algorithm, which is a kind of optimization based on the group intelligence algorithm. In essence, swarm intelligence algorithm is a bionic intelligence optimization algorithm that aims to imitate the division of labor and cooperative behavior mechanism of nature's biological groups, which has the characteristics of diversified algorithms and strong optimization capability, including particle swarm algorithm, artificial bee swarm algorithm, bacterial foraging algorithm, etc. [4]. The "two-way exhaustive" hybrid swarm algorithm is based on the fusion of particle swarm and bacterial foraging algorithms, with the addition of artificial fish swarm algorithm and fruit fly algorithm, but the overall algorithm is mainly based on the structure of particle swarm algorithm, and the fusion of the "two-way exhaustive" hybrid swarm algorithm. The hybrid swarm algorithm has strong data mining ability and convergence in addition to the strong merit-seeking ability, which can quickly distinguish the superior and inferior algorithms and finally realize the intelligent optimization of the population algorithm. In order to improve the global optimization ability of the thrust distribution algorithm, this paper also actively introduces chaos operator, fly operator and concentration operator on the basis of the "two-way exhaustive" hybrid swarm algorithm, and realizes the maximum optimization of the algorithm and improves the optimization ability of the algorithm by means of two-way optimization and exhaustive population seeking [5].

### 3.2. Algorithm execution steps

Step 1: Initialize the population, which can be achieved using chaos operators. Chaos operator not only has strong randomness and ergodicity, but also can improve the global optimality-seeking ability of the algorithm and avoid the algorithm to fall into local extreme value points, so as to achieve the optimal initialization process for each individual in the population group, and finally the population initialization [6].

Step 2: Calculation of individual fitness values and global optimum values.

Step 3: Population evolution and individual update algorithms, choosing a two-way optimal search method to achieve evolution and an exhaustive search method to achieve update.

Assuming that the individual, denoted by "", is the "optimal solution for each individual"; and the global optimal solution is denoted by "", then the population evolution process is as follows.

(1) Update each individual, and the update definition equation is as follows.

$$X_i(t+1) = X_i(t) + \Delta X_i(t) \tag{3}$$

Where

$$\Delta X_i(t) = rand() \times sl_1 \times \frac{X_i(t) - X_j(t)}{\|Xi(t) - Xj(t)\|} + rand() \times sl_2 \times \frac{X_i(t) - P_{gbest}}{\|X_i(t) - P_{gbest}\|}$$

(2) calculate the individual adaptation value and judge whether it is optimized, and update again according to the calculation result and judgment result, the definition equation is as follows

$$X_i(t+1) = X_i(t) - \Delta X_i(t) \tag{4}$$

Then continue to optimize according to equation 4, the definition equation is as follows.

$$X_i(t+1) = X_i(t) + c_p^i \Delta X_i(t)(c_p^i > 1) \tag{5}$$

(3) To judge whether optimization is obtained or not, and then continue to update and execute, defined equation as follows

$$c_p^i = c_p^i(1 + c1 \times rand()) \tag{6}$$

Update and optimize each individual according to equation 6, defined as follows

$$X_i(t+1) = X_i(t) - c_p^i \Delta X_i(t)(c_p^i > 1) \tag{7}$$

The execution in Equation 7 is defined as follows

$$c_p^i = c_p^i(1 + c2 \times rand()) \tag{8}$$

After updating and optimizing each individual need to determine whether the number of attempts on the set value (can be set to m), if the individual's fitness value still does not reach the optimum after m attempts, it is necessary to execute the random operator and retain the current optimum individual fitness value; if the optimum is reached after m attempts then end the individual evolution, and then update the global optimum [7].

Step 4: Local optimization and group species update.

(1) Local optimization, which is essentially the optimization of the optimal individual and the worst individual, is defined by the following equation.

Optimal individual local optimization defined Eq.

$$X_i(t+1) = X_i(t) + rand() \times v_1 \tag{9}$$

Note: In the standard range of values, the smaller the value, the better.

Worst individual local optimization is defined as follows

$$X_i(t+1) = X_i(t) + rand() \times v_2 \tag{10}$$

Note: The larger the value in the standard range, the better.

(2) Population update. The population can be updated using the concentration operator (including the distance operator and the fitness value operator). Assume that the value of the first individual is the value of the fitness of the first individual; the value of the first individual is the value of the fitness of the first individual; the distance between individuals, if the center of the first individual, can be used to indicate the distance between the first individual and the first individual [8], defined as follows.

$$D_i^j = \left\| X_i - X_j \right\| \tag{11}$$

If the difference of fitness values is defined as, the defining equation is

$$E_i^j = \left\| Y_i - Y_j \right\| \tag{12}$$

The defining equation of the distance concentration operator (set to) is derived from Eq. 10 and Eq. 11, i.e.

$$O_i^j = \begin{cases} 1 & D_i^j \le D_{set} \\ 0 & D_i^j > D_{set} \end{cases} \tag{13}$$

Note: is the set constant.

Finally, the fitness value is calculated and the population is updated, and the fitness value operator (set to) is defined by

$$F_i^j = \begin{cases} 1 & E_i^j \le E_{set} \\ 0 & E_i^j > E_{set} \end{cases} \tag{14}$$

## 4. Optimal allocation of thrust based on supervision and switching and swarm intelligence

The key of optimization lies in the sector constraint problem processing and subsector combination application logic, and the specific optimization is as follows.

### 4.1. Sector constraint problem processing

The optimal thrust allocation based on supervision and switching and group intelligence involves the use of multiple thrusters, and it is necessary to plan the thrust exclusion zone of the thrusters when setting and thrusters to avoid mutual interference among the thrusters. In this paper, CybershipIII thruster is selected, CybershipIII no-go zone settings are shown in Figure 1 (the shaded sector is the thrust no-go zone).

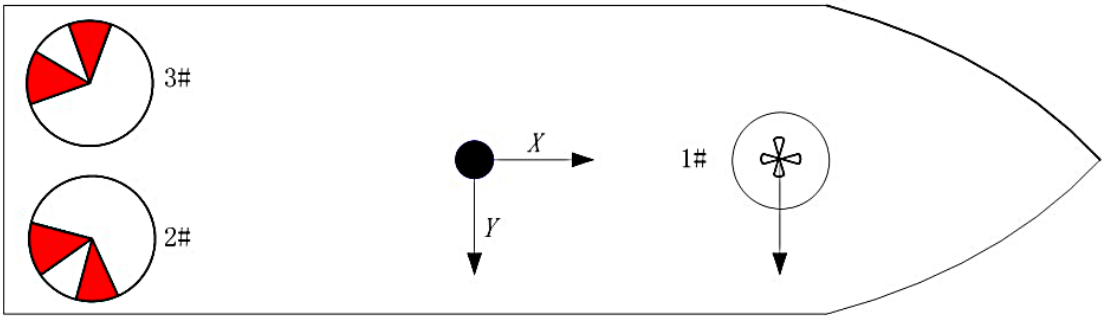



**Figure 1** Cybership III thruster no-zone settings schematic

Because the group intelligent optimization algorithm ("two-way exhaustive" mixed group algorithm) is used to find the optimum thrust distribution, the convexity and non-convexity of subsectors can be ignored, and the thrust sector combination is directly divided into four subsector combinations, and the relevant parameters are shown in Table 1.

**Table 1** Sector combinations and their parameters

| Sector combinations | $\alpha_2$ / ° | $\alpha_3$ / ° |
|---|---|---|
| Combination1 | [-160, 80] | [-80, -160] |
| Combination2 | [120, 150] | [-150, -120] |
| Combination3 | [-160, 80] | [-80, -160] |
| Combination4 | [120, 150] | [-150, -120] |

Note: $\alpha \in \Re^n$ - azimuth angle of each thruster.

### 4.2. Application logic of subsector combinations

Because the sector has a thrust exclusion zone, the thrust distributor (called thruster above) cannot continuously change the rotation angle. If the sector is composed of multiple thrusters, it is necessary

to divide the composed sector into several subsectors (or subsector combinations), and then carry out thrust distribution and optimization for the subsectors or subsector combinations respectively, and also need to carry out sector switching during the optimization process to quickly solve the subsector The subsector combination application logic problem. The main role of the supervision and switching function in the processing of the subsector combination application logic problem is to ensure that the set requirements $\tau_c - B(\alpha) f$ can be met so as to reduce the total power consumption of the thruster and the incidence of mechanical wear [9].

### 4.3. Thrust distribution optimization

The thrust distribution optimization is achieved by using the "two-way exhaustive" mixed group optimization algorithm with supervision and switching to iteratively find the optimal thrust distribution algorithm and then realize the thrust distribution optimization. The steps of iteration are as follows.

Step 1: Initialization. Mainly for the initialization of the main parameters, including the thrust of the thruster, thruster azimuth, thruster combined force and moment, thrust coefficient matrix, thrust limit value, thrust maximum rate of change, position construction matrix, etc., of which the thruster azimuth is the most important, through the "two-way exhaustive" mixed group optimization algorithm The thrust and azimuth angle are obtained, and the individual fitness value is calculated by the system of linear equations (see Equation 1 and Equation 2).

Step 2: Search for the entire subsector to find the optimum. Assuming that the thrust allocation solution at the previous moment is ( $f_P, \alpha_P$ ), the subsector can be searched using the "two-way exhaustive" mixed group optimization algorithm, and energy consumption, force and moment deviation, and singular structure are calculated, and then the optimal thrust allocation solution ( $f_{best}, \alpha_{best}$ ) and subsector $I_{best}$ are obtained.

The prerequisite and basis for obtaining the optimal thrust distribution solution ( $f_{best}, \alpha_{best}$ ) and subsectors $I_{best}$ is to meet the set requirements $\tau_c - B(\alpha) f$ (i.e., solutions that meet certain requirements). If the current subsector $\tau_c - B(\alpha) f$ does not have a solution that satisfies a certain requirement, the thrust exclusion zone needs to be reset, and then a reliable thrust allocation solution and subsector can be obtained using the "two-way exhaustive" mixed-squad optimization algorithm. It should be noted that when using the "two-way exhaustive" mixed-squad optimization algorithm to obtain the optimal thrust distribution solution and subsectors, the thrust exclusion zone is set to effectively avoid mutual interference among the thrusters, so the cost function is set without considering the angle change rate constraint, and the optimal subsectors can be searched directly [10].

Step 3: Determine the optimal thrust distribution sector. The global optimal thrust allocation sector can be found by using the dwell time switching and hysteresis switching techniques, and then the optimal thrust allocation sector can be determined by considering various factors (such as angle change rate, switching time and cost function change, etc.) and combining the "two-way exhaustive" mixed group optimization algorithm to obtain the optimal thrust allocation solution, and finally the optimal thrust allocation sector is determined on this basis[11] . The optimal thrust allocation sector is determined on this basis [11]. In obtaining the optimal thrust allocation sector, the sector switching logic is mainly applied, and the expression of the calculation logic is as follows.

$$Iw = \begin{cases} Ibest & if t > t_{dts} \; and (J_P(T_{best}) < (J_P(I_n) - J_{P\lim})) \\ & and((S(I_{best}) < (S(I_n)(1 + S_{dt}s))) \\ I_P & if (t < t_h) and (I_{best} = I_P) \\ I_n & otherwise \end{cases} \tag{15}$$

The description of Equation 15 is given in Table 2.

**Table 2** Explanation of the expressions of the calculation logic

| Formula parameters | Parameter description | Note |
|---|---|---|
| $I_{best}$ | Optimal subsector combinations for global optimization search | |
| $I_n$ | Current optimal subsector combination | |
| $I_P$ | $I_n$ Previously selected optimal subsector combination | |
| $t$ | $I_P$ Time until the present moment when switching to $I_n$ | |
| $t_{dts}$ | Minimum switching time for dwell time switching | |
| $t_h$ | Maximum return switching time($t_h < t_{dts}$) | set to prevent switching due to transient disturbances |
| $J_{P\lim}$ | Minimum value of the change of the surrogate function | Change of the function to be limited in the case of lagged switching |
| $S(\cdot)$ | Accumulated sum of relaxation variables | |
| $S_{dts}$ | Maximum value of slack variable accumulation sum change | Unit: % |

Step 4: According to the optimal subsector combination and the corresponding optimization algorithm to determine the thruster azimuth and thrust size, according to whether the subsector combination switch, the current subsector actual situation to solve the azimuth and thrust size, as follows.

(1) When $I_n = i_{now}$ and $I_{best} = i_{now}$, the current optimal sector combination is $I_{best} = i_{now}$, on the basis of the "two-way exhaustive" mixed group optimization algorithm to calculate the thruster energy consumption, force and torque deviation, azimuth change rate and other parameters, and finally combined with the global optimum angle to solve the thruster azimuth and thrust size [12].

(2) When $I_n = i_{now}$ and when $I_{best} \neq i_{now}$, or $I_n \neq i_{now}$ and $i_{now}$ not in the forbidden area, can directly use the "two-way exhaustive" mixed group optimization algorithm to calculate the thruster azimuth and thrust magnitude.

(3) In other cases, first determine the thruster azimuth size, and then use the "two-way exhaustive" mixed group optimization algorithm to solve the thruster thrust size [13].

Step 5: Output the thrust distribution result and determine whether this thrust distribution is the last thrust distribution solution, if it is, then end, otherwise execute step 2.

## 5. Conclusions

Thrust distribution is the key to the efficient and safe operation of the ship power positioning control system, and has always been of great concern and importance to the staff concerned. Although the ship power positioning control system built based on traditional thrust allocation algorithm can cope with common thrust allocation problems (such as energy consumption problem and power problem), it is difficult to cope with the problems caused by thrust limit of thrusters, thrust rate of

change limit, azimuth rate of change limit, mechanical wear and tear, restricted area limit, etc. Therefore, the thrust allocation algorithm must be optimized continuously to improve the ship power positioning The thrust distribution algorithm must be optimized continuously to improve the ship power positioning system function and reduce the incidence of various thrust distribution problems. The thrust allocation algorithm based on supervision and switching and group intelligence can effectively close the shortcomings of the traditional thrust allocation algorithm, thus optimizing the function of the ship power positioning control system and achieving the purpose of efficiently solving various thrust allocation problems. Therefore, based on the understanding of the ship power positioning control system and thrust distribution, the above proposes the "two-way exhaustive" mixed swarm optimization algorithm, supervision and switching mechanism (new thrust distribution algorithm), and then integrates the advantages of various swarm intelligence algorithms to expand the algorithm search space and improve the global search capability and convergence of the algorithm. And the thrust optimization allocation based on supervision and switching and swarm intelligence is analyzed, hoping to play a positive role in the actual thrust allocation optimization work.

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