The method of comprehensive optimization analysis for catamaran unmanned vehicle

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Abstract. In order to obtain the optimal design of catamaran unmanned vehicle type, based on a USV type, and a mathematical model is created. Use the form of the product of the power exponential function for each performance objective function, and then combine the penalty function to construct the fitness function suitable for the catamaran unmanned, combine the constructed optimization mathematical model with the intelligent optimization algorithm, and design the comprehensive optimization program for the vehicle type. Based on the above software platform, the research and analysis of genetic algorithm, particle swarm algorithm and chaos algorithm are conducted. The results show that the highest efficiency of selected catamaran ship model; further analysis of the four ship types M_{08}, M_{10}, M_{15}, M_{16}in the two different high-speed sections of the optimal ship type, and finally get the M_{10} optimal, so as to optimize the design.

Keywords: Catamaran unmanned ship, Genetic algorithm, Particle swarm algorithm, Chaos algorithm, Comprehensive optimization.

1 Introduction

As a water surface unmanned vehicle (USV), a water surface unmanned equipment, can take the initiative to complete its own tasks. Compared with ordinary carriers, it has the characteristics of small volume, good manoeuvrability and fast speed [1]. With the rapid development of relevant technologies, it is equipped with independent operating system and can be equipped with radar, underwater detection sonar and mechanical operating system on unmanned vehicles, which can independently complete the more difficult work than manned vehicles. Unmanned catamaran has become a current research subject with its large deck area, good stability, high manoeuvrability and excellent mobility. The overall optimization of surface unmanned craft is very important for the design and development of unmanned craft, because the unmanned vehicle type optimization has a great impact on its design and development [2].

Multidisciplinary design optimization is often used to explore complex system design for subsystem interactions and to coordinate relevant elements of each system [3]. Since the design process involves multiple disciplines, the USV comprehensive optimization is the main part of the USV design. For this reason, this article is based on the multidisciplinary

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comprehensive optimization software compiled by the team and made corresponding improvements on this basis. After the computational analysis of several different algorithms, excellent computing results are obtained, reflecting the accuracy and reliability of the optimization [4].

In this paper, we establish a comprehensive optimization mathematical model by studying doubly unmanned vehicles. According to this mathematical model, the comprehensive optimization design software including genetic algorithm [5], particle swarm algorithm and chaotic algorithm is studied.

2 Comprehensive optimized mathematical model

2.1 Design variable

The design variables were selected in this paper, including: propeller diameter (D_P), propeller speed (N), propeller disk ratio (A_E / A_0), design the total width of the waterline (Bl), propeller pitch ratio (P_{DP}), rudder area (A_R), lateral spacing of side hull (b), design speed (V), ship design draft (d), displacement (Δ), wet area (S), length (L), breadth molded $(B)$and so on.

2.2 Objective function

This paper uses a multi-objective optimization design. In general, the more objective the function, the more design objective functions are required. The depth considers the speed and maneuverability of the catamaran unmanned vehicle. Thus, these subobjective functions are transformed into total objective functions through a combination of product of power exponents. The formula follows:

$$D(\chi)=W_1(\chi)^{\alpha 1}\times W_2(\chi)^{\alpha 2} \tag{1}$$

α_1 , α_2 respectively represent the weights of rapidity, maneuverability Rapidity builds an optimized sub-objective function based on the naval coefficient. The naval coefficient is used to estimate the power and navigation speed of the ship host, or to compare the speed coefficient of ships of the same type. See the formula for the naval coefficient., select the fast sex reference coefficient, and the expression is as follows;

$$W_1(\chi)=\frac{v^3\Delta^{2/3}}{P_s} \tag{2}$$

The maneuverability of the ship mainly include s directional stability, swingability, traceability and stoppingability, etc. Here, we only need to consider the directional stability. The equation is as follows:

$$W_2(\chi)=C'=Y_v'N_r'-N_v'(Y_r'-m') \tag{3}$$

$$m'=2C_{bo}\frac{B_oT}{L^2}$$

$$Y_v' = -\pi(1+0.4C_{bo}B_o / T)(T / L)^2$$

$$Y_r' = -\pi(-0.5+2.2B_o / L - 0.08B_o / T)(T / L)^2$$

$$N_v' = -\pi(0.5+2.4T / L)(T / L)^2$$

$$N_r' = -\pi(0.25+0.039B_o / T - 0.56B_o / L)(T / L)^2$$

C is the stability criterion

2.3 Constraint condition

2.3.1 Equal constraints

(1) Hydrostatic buoyancy constraint

$$\Delta = 2\rho LBTC_B \tag{4}$$

(2) Torque balance constraint

$$\frac{\eta_R \eta_S P_S}{2\pi N} = K_Q \rho N^2 D_p{}^5 \tag{5}$$

(3) Thrust balance constraint

$$R_t = 2K_{T1}\rho N_1{}^2 D_p{}^4 (1-t) \tag{6}$$

2.3.2 Inquality constraints

(1) The propeller shall meet the vacuole requirements:

$$(1.3+0.3Z)T_e / ((P_0 - P_v)D_p{}^2) + K - (A_E / A_0) \le 0 \tag{7}$$

(2) According to the stability specification of the ship, the high stability of the positive float should be greater than 0.3 meters:

$$GM > 0.3 \tag{8}$$

(3) The total height shall be larger than the flipped draft:

$$T_1 < H_1 + H_2 \tag{9}$$

2.4 The punishment function establishment

The penalty function is a restrictive function and is a restrictive condition in problem solving. The penalty functions involved in this paper are equation constraints and inequality constraints, respectively.

where the penalty value of the constraint composition is the product of all the constraint penalty values, take the buoyancy constraint in the equation constraint and the floating constraint equation is:

$$\Delta = 2\rho LBTC_B \tag{10}$$

The corresponding point penalty value is:

$$b_1(x) = e^{-F_1|\Delta - 2\rho LBC_B|/(2\rho LBC_B)} \tag{11}$$

$P_1(x)$ is assumed as the product of the three equality constraint penalty function values, and $P_2(x)$ as the product of the three inequalities, so there are total penalty function values $P(x)$:

$$P(x) = P_1(x) \times P_2(x) \tag{12}$$

2.5 Fitness function establishment

In order to better judge the quality of a solution, a fitness function is introduced. The results obtained by multiplying the total objective functions $D(x)$ and penalty functions are as follows;

$$A(x) = D(x) \times P(x) \tag{13}$$

3 Optimization method and calculation strategy

Set the initial weights for this article as follows. Analysis was performed using three algorithms: genetics, chaos, and particle swarms.

	Weight Settings
Rapidity	1.25
Dirigibility	0.8

3.1 Genetic algorithm

Genetic algorithms (GA) are designed according to the evolutionary laws of organisms in nature. It is a process of natural selection and survival of the fittest. Finally, it selects the best swarm, which is a search algorithm based on natural selection and population genetic mechanism. The algorithm uses computer simulation operations to transform the solution process to the selection, crossover, variation of chromosomal genes in biological evolution.

3.2 Particle swarm algorithm

Particle swarm optimization (PSO) is a global search algorithm that simulates the swarm intelligent foraging behavior of birds and fish in nature. Meanwhile, it is also a stochastic search algorithm that simulates biological activities and swarm intelligence in nature.

3.3 Chaos algorithm

Chaos optimization algorithm (CA) is an optimization algorithm with random chaotic variables, ergodic nature and regularity.

4 Count

The optimal algorithm was chosen first

The population size was 400, the number of iterations 3000-7000, variation probability 0.01, cross probability 0.75, Captain Froude number (0.35-0.47), displacement 40 tons, propeller diameter 0.45-0.55m, M_{08} as an example, the three algorithms were calculated as follows;

Table 1. M_{08} genetic algorithm.

GA	3000	4000	5000	6000	7000
Adaptation function values	4351.45	4363.07	4373.09	4373.13	4373.14
Total target function value	4354.15	4365.78	4375.80	4375.98	4376.55
Fast function values	219.23	220.52	222.58	222.69	222.73
Operative function values	7.58	7.61	7.65	7.65	7.66

Table 2.The M_{08} Chaos algorithm.

CA	10000	50000	100000	150000	200000
Adaptation function values	4003.95	4094.81	4180.30	4218.74	4194.50
Total target function value	4006.48	4097.27	4182.85	4221.38	4197.04
Fast function values	222.04	190.11	202.03	224.17	197.04
Operative function values	6.87	9.01	8.41	7.23	8.78

Table 3. M_{08} Particle swarm algorithm.

PSO	3000	4000	5000	6000	7000
Adaptation function values	4335.15	4357.78	4357.83	4357.86	4358.55
Total target function value	4337.82	4360.46	4360.52	4360.54	4361.25
Fast function values	216.03	217.99	219.96	219.97	220.50
Operative function values	7.92	7.86	7.75	7.89	7.72

All constraints were met by conditions above 99%.

Comparing the function values of the three algorithms for a certain time of time, down to the following table 4;

Table 4. Algorithm comparison.

method/time	GA/00.58	PSA/01.08	CA/01.18
Fitness function value	4373.07	4357.78	4194.50
The total objective function value	4375.78	4360.46	4197.04

As can be shown from the figure above, for the M_{08} ship type, the genetic algorithm can use the least time and the larger the function value, so the genetic algorithm is the most appropriate. It can be learned from Table 1 that the data thereafter are close to the steady state when the genetic algebra approaches around 5000.Therefore, 5000 generations were used as stable genetic numbers in genetic algebras and used as the basis for subsequent calculations.

The number of iterations is the growth mechanism; the number of iterations 5000, population size 300-700, variation probability 0.01; crossover probability 0.75, Captain

Froude number (0.35-0.47), displacement 40 tons, propeller diameter 0.45-0.55m. The calculation results are shown in Table 5:

Table 5. M_{08} Calculation results of different population sizes.

Population size	300	400	500	600	700
Adaptation function values	4302.93	4335.93	4373.08	4373.09	4373.98
Total target function value	4305.64	4339.64	4375.79	4375.85	4375.99
Fast function values	218.40	220.40	222.78	222.88	222.94
Operative function values	7.55	7.60	7.63	7.64	7.65

The population calculation after determining 5000 times, it is clearly obtained from table 5 above that the population size change also has some effect on the target function value, when the population size reaches 500, the overall data tends to stabilize, so the population size chooses 500 for the subsequent calculation.

As with the above method, the M_{10}, M_{15}, and M_{16} ship models were analyzed by three algorithms in the same time, and the analysis results are as follows;

Table 6. M_{10}.

Method	GA	PSA	CA
Fitness function value	4298.85	4247.78	4247.24
Fitness function value	4301.42	4250.40	4249.79

Table 7. M_{15}.

Method	GA	PSA	CA
Fitness function value	4519.95	4503.36	4282.18
Fitness function value	4522.75	4506.15	4284.79

Table 8. M_{16}.

method	GA	PSA	CA
Fitness function value	4708.90	4619.93	4521.38
Fitness function value	4711.95	4622.97	4524.32

All constraints were met by conditions above 99%.The table shows that the genetic algorithms are the optimal algorithms among the three algorithms.

In the first high-speed section, the captain Froude number (0.35-0.47), the optimal ship type is calculated for four ship types through the genetic algorithm. The population size is 500 and the genetic number is 5000, and the results are as follows;

Table 9. Calculated results of different ship types.

method	M_{08}	M_{10}	M_{15}	M_{16}
Fitness function value	4427.51	5042.02	4520.23	4708.98
Fitness function value	4430.21	5045.03	4523.03	4712.03

The table shows that the M_{10} is the best in this expressway section.

In the second high-speed section, the captain Froude number (0.50-0.65), the optimal ship type was calculated for four ship types through the genetic algorithm. The population size 500 and the genetic number 5000 were calculated as follows;

The table shows that the M_{15} is optimal in this highway section.

In the first expressway section (0.35-0.47), M_{10} is the research subject, respectively taking the captain Froude number 0.35-0.37, 0.37-0.39, 0.39-0.41, 0.41-0.43, 0.43-0.45, 0.45-0.47 for discrete calculation. The results are shown in the following figure;

Table10. Calculated results of different ship types.

method	M_{08}	M_{10}	M_{15}	M_{16}
Fitness function value	3556.68	3784.42	3816.58	3238.98
Fitness function value	3558.82	3786.68	3818.85	3241.08

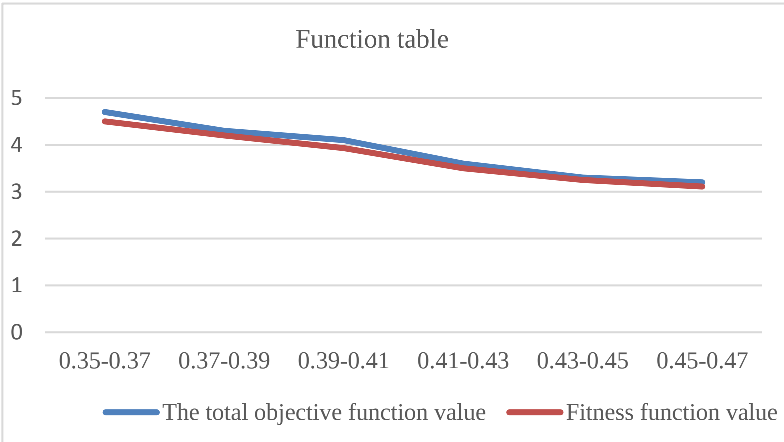

Fig. 1. Calculated results of different high-speed sections.

As can be seen from the figure above, the M_{10} has the best performance in a high-speed section of 0.35-0.37.

In the second expressway section (0.50-0.65), M_{15} is the research subject, respectively taking the captain Froude number 0.50-0.53, 0.53-0.56,0.56-0.59,0.59-0.62,0.62-0.65 for discrete calculation. The results are shown in the following figure;

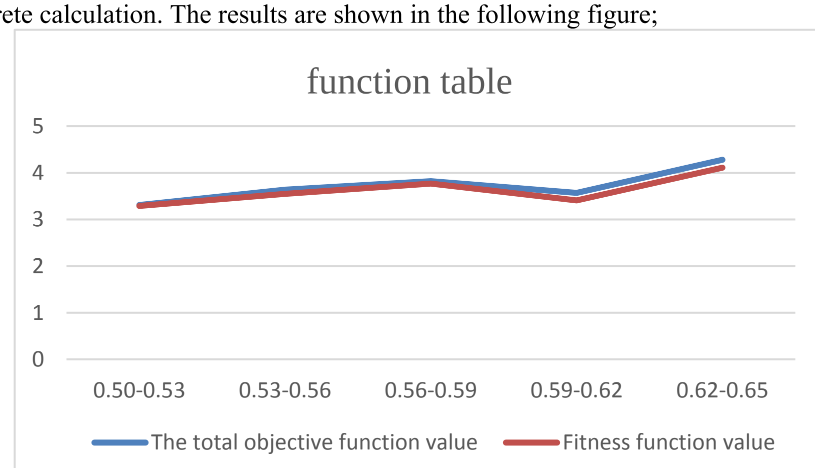

Fig. 2. Calculated results of different high-speed sections.

As can be seen from the figure above, the M_{15} performs the best in the high-speed section of 0.62-0.65.

4.1 Best optimization results

According to the best calculation result file, the values under optimization are as follows: main hull length 24.56m, wide 2.25m, draft 0.77m, displacement 39.9t, Froude number

0.36;midship section coefficient 0.80, block coefficient 0.471,waterplane coefficient 0.75, propeller diameter 0.54m, prismatic coefficient 0.59, disk ratio 0.66, pitch ratio 0.79.

5 Conclusion

In this paper, we construct total objective functions, constraints and penalty functions with fast speed and manipulability, A comprehensive optimization mathematical model of this USV is established, Four ship types, M_{08}, M_{10}, M_{15}, and M_{16}, were also calculated using the genetic, chaotic, and particle swarm algorithms, Finally, the most suitable algorithm is the genetic algorithm for the subsequent calculation, The optimal ship type was then analyzed in two different high-speed sections, Then, the optimal discrete analysis of ship type within the corresponding high speed section, The optimal velocity segment is obtained. The performance of M_{10} is the best in the high-speed section of Captain Froude number 0.35-0.37; the performance of M_{15} is the best in the high-speed section of Captain Froude number 0.62-0.65; The comparison of the two shows that the M_{10} has better performance, and the best optimized calculation result is obtained based on this.

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