Research on Optimization of Main Engine Speed of Inland Ship Based on Genetic Algorithm

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Abstract. This paper aims at reduced total fuel consumption of voyage by obtaining navigation data of inland ships, and established the fuel consumption prediction model of the main engine in the segment through studying the navigation route by sections according to the characteristics of the navigation environment, and solved the problem with the help of genetic algorithm to obtain the best main engine for each segment main engine speed. The results show that: (1) The error of the neural network model verification data set is mostly within 6%, and the model performance is good; (2) The experimental ship from Nanjing to Jingzhou from June to September adopts the optimized main engine speed to save 0.6232t of fuel, which is 4.06% lower than the original total fuel consumption. This method has practical and guiding significance for reducing the cost of inland ship navigation and improving the ecological environment of the Yangtze River.

Keywords. Neural networks; genetic algorithm; segment division; main engine speed.

1. Introduction

Water transportation plays a huge role in the development of the national economy, but it also leads to high energy consumption and environmental pollution problems. Statistics from the Fourth Greenhouse Gas Research Report of the International Maritime Organization (IMO): About 2.89% of global greenhouse gas emissions in 2019 were generated by ships [1]. It is expected that by 2050, this level will increase by 50-250%. In 2020, the IMO established a limit standard for global ship fuel pollution emissions not to exceed 0.5% [2]. In recent years, due to the increase in fuel prices, shipping companies have faced tremendous challenges in reducing operating costs and improving market competitiveness. In addition, the “Kyoto Protocol” and the IMO Marine Environmental Protection Committee (MEPC), which require the reduction of carbon dioxide emissions, have been putting pressure on shipping companies to effectively increase the energy consumption of ships [3]. Optimization and improvement of energy consumption for inland waterways is the primary choice for shipping companies to reduce operating costs and develop friendly environmental and efficient shipping methods.

In different navigation environments, the route is divided into segments and the diesel engine speed is optimized separately. Low-speed navigation can reduce fuel costs within a certain limit, and ship speed is greatly affected by the diesel engine speed. On the premise of maintaining SLA (Service Level Agreement), determining the best speed that can minimize fuel consumption is an important management decision issue for shipping companies. Lee et al. [4] use weather archives to estimate the actual fuel consumption function of the speed optimization problem, use Copernicus data as big data source, consider the impact of the weather environment, apply data mining technology, and use particle swarm optimization algorithms to solve the minimum fuel consumption and the maximum SLA Pareto
optimal solution. Song et al. [5] by combining the characteristics of the existing shipping market, a reasonable dual-objective fleet configuration model was established, the genetic algorithm model was used to obtain the final optimization plan, and the effectiveness practicability of the model were verified through examples. Yan et al. [6] through big data analysis of the corresponding environmental factors, the distributed parallel k-means clustering algorithm is used to finely divide the route path, and the ship’s propeller energy transfer relationship is analyzed to establish a ship energy consumption optimization model for multiple environmental factors, in different sections, optimize the speed of the diesel engine. Wang et al. [7] by using built up ship energy efficiency and navigation environment data monitoring system for real-time collection and monitoring of the navigation environment such as shaft power, diesel fuel consumption, water speed, relative wind speed, and channel water depth. Pagoropoulos et al. [8] propose the use of support vector machines to implement ship energy efficiency assessment, and the verification results show that the proposed method is effective. Zacco et al. [9] a three-dimensional dynamic planning method for ship navigation considering meteorological factors is proposed, which can effectively improve the safety of ship navigation and reduce the level of ship energy consumption. Wang et al. [10] by adopting Dijkstra’s algorithm, considering multi-factor and multi-optimization-oriented ship navigation optimization decision-making, navigation safety and energy efficiency level of the ship can be improved and the requirements of emission regulations can be improved. Sui et al. [11] had pointed out that advancing the optimized combination of system control, energy management and voyage planning can further reduce fuel consumption and carbon emissions in the shipping industry. The above-mentioned research mainly focuses on the optimization of the energy consumption of sea-going vessels, and few systematic studies have been carried out on inland ships with a large volume and a more complex energy consumption status. The energy efficiency of inland ship is greatly affected by the navigation environment, including wind speed, wind direction, water flow speed, and river bending radius. The complexity of the navigation environment makes it extremely difficult to determine the optimal speed under different environmental conditions to achieve the best energy efficiency. In this research, the experimental ship route is divided into segments, the BP-neural network is used to accurately predict the fuel consumption of the ships in the Yangtze River, and the genetic algorithm is used to optimize the speed of the ship diesel engine, and guide the ships to adopt the optimized diesel engine speed in the corresponding segments, the main engine speed can reduce fuel consumption, reduce operating costs, and achieve the purpose of energy saving and emission reduction.

2. The Establishment of Main Engine Fuel Consumption Model

2.1. Research Object
This paper takes an oil tanker on the Yangtze River as the research object. The main dimensions of the oil tanker are shown in table 1. The main engine of the oil tanker is two large-scale low-speed two-stroke diesel engines, No. 0 light diesel is used as the main engine fuel. The main technical data of the diesel engine is shown in table 2. The propeller diameter is 2500mm, and the propeller pitch is 1960mm.

| Length (m) | Tonnage (t) | Type depth (m) | Type width (m) | Net tonnage (t) | No-load draught (m) | Full draught (m) |
|------------|-------------|----------------|----------------|----------------|-------------------|-----------------|
| 105        | 5383        | 6.6            | 16.2           | 1486           | 1.273             | 4.8             |

Table 1. Main parameters of the basic size of the ship.

| Number of cylinders (pcs) | Cylinder diameter (mm) | Stroke (mm) | Rated power (kw) | Rated speed (r/min) |
|---------------------------|------------------------|-------------|------------------|---------------------|
| 6                         | 210                    | 290         | 551              | 750                 |

Table 2. Main parameters of marine diesel engine.

2.2. Division of Inland Waterways
The hydrological situation of inland waterway is more complicated, and inland ships will be affected by many factors during their navigation, such as water flow speed, river channel width, river bending

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radius, wind speed, wind direction, water depth and other factors. These factors directly affect the fuel consumption of the main engine. Therefore, it is particularly important to segment the waterway according to the navigation environment.

In this study, the Nanjing-Jingzhou section is selected, and the data selected are the operating data of the experimental ship from June to September. Among them, the flood period is from June to September, the water level is high and the water flow velocity is high. According to the topographic characteristics of the channel and the characteristics of hydrological environment, the route is roughly divided into 5 parts: Nanjing to Tongling, Tongling to Jiujiang, Jiujiang to Wuhan, Wuhan to Yueyang, and Yueyang to Jingzhou.

2.3. Data Preprocessing
Ship operation data is collected by ship monitoring equipment every 20 seconds, and the average value of the data is integrated into one group every 30 minutes. After the data collection is completed, an important process is to preprocess the data. Good data preparation is essential for subsequent main engine fuel consumption modeling. Irrelevant data and erroneous data may lead to excessive noise signals. Only by removing useless information can the data features be effectively captured, analyzed and utilized. At the same time, the navigation data collected during the operation of the ship has the characteristics of multi-source and heterogeneous. In order to eliminate differences, the selected data must be normalized to achieve comparability at different scales [12].

2.4. The Establishment of Objective Function
Based on the above-mentioned division of inland waterways, the fuel consumption model of the ship on each section is modeled separately, with the goal of the lowest total fuel consumption of the ship on the five sections as the goal, and the objective function is established for the fuel consumption model on each section. In this paper, the predicted value of the diesel engine fuel consumption prediction model is used as the fitness value of the genetic algorithm, and the fuel consumption prediction network is the fitness function, and the main engine in the input parameters of the fuel consumption model is optimized.

At the same time, in the process of ship navigation, considering the safety of ship navigation, ensuring the normal operation of the ship and the constraints of the diesel engine itself, the establishment of the objective function needs to meet the following constraints: (1) The ship sailing time cannot exceed the estimated time of arrival (ETA); (2) In order to ensure a good cooperation between the governor and the diesel engine, the speed of the diesel engine must be between the highest speed and the lowest speed of the diesel engine; (3) In order to avoid friction damage to the internal components of the main engine, the ship’s speed must be between the highest design speed and the lowest design speed.

Objective function:

\[
min F = \min \left( \sum_{i=1}^{5} f_i(n_i) \right)
\]

Restrictions:

\[
\sum_{i=1}^{5} \frac{s_i}{v_i} \leq ETA
\]

where F is the total fuel consumption of the voyage; \( f_i \) is segmented fuel consumption; ETA is the estimated time of the voyage; \( s_i \) is the distance of the voyage; \( v_i \) is the speed of the ship in the voyage.

\[
n_{min} \leq n_i \leq n_{max} \quad v_{min} \leq v_i \leq v_{max}
\]

2.5. Neural Network Model for Predicting Main Engine Fuel Consumption
The fuel consumption of inland ship depends not only on the ship itself, but also on environmental factors, this study uses the back propagation neural network (BP-ANN) learning algorithm to analyze the multi-parameter sensitivity of fuel consumption, based on the main engine speed, tail shaft speed,
load capacity, wind speed, wind direction, water flow speed, water depth, channel width, and river bending radius, ship speed, etc. as input, fuel consumption as output, build a three-layer structure of the main engine fuel consumption neural network model. It can be seen from figures 1-2 that when the ship navigation for 30 minutes, the prediction error of the model’s fuel consumption is mostly within ±4kg, and the prediction error percentage is mostly within ±6%. Therefore, the neural network model performance meets the requirements.

3. Optimization of Main Engine Speed Based on Genetic Algorithm

3.1. Genetic Algorithm

After the objective function and constraint conditions are determined, the select, cross, mutation and other related documents required by the genetic algorithm are written. Select, cross, and mutation constitute the genetic operation of genetic algorithm; parameter coding, initial population setting, fitness function design, genetic operation design, control parameter setting, these five elements constitute the core content of genetic algorithm.

The evolutionary number is 500; the population size is 50; the crossover probability is 0.3; the mutation probability is 0.2. The genetic algorithm process is shown in figure 3.
3.2. Optimization Results and Discussion

The optimization results of the main engine speed of each segment are shown in table 3 and figure 4, including the original main engine speed and fuel consumption of different Nanjing-Jingzhou segments, the optimized main engine speed, fuel consumption and the difference between the two. Among them, the optimized engine speed of the Nanjing-Tongling and Jiujiang-Wuhan segments is greater than the original engine speed. The optimized engine speed of the Tongling-Jiujiang, Wuhan-Yueyang and Yueyang-Jingzhou segments is less than the original engine speed. The optimization method of the ship's main engine speed not only ensures that the sailing ship can reach the destination on time, avoids the wear of the internal components of the ship's main engine to ensure the good cooperation of the diesel engine and the safety of navigation, but also saves fuel.

Table 3. Comparison of original fuel consumption and optimized fuel consumption of flight segment.

| Segmentation (number) | Mileage (km) | Original speed (r/min) | Optimized speed (r/min) | Original fuel consumption (t) | Optimized fuel consumption (t) | Difference (t) |
|-----------------------|--------------|------------------------|-------------------------|------------------------------|-------------------------------|----------------|
| 1                     | 205          | 517                    | 520                     | 3.0000                       | 3.0052                        | -0.0052        |
| 2                     | 239          | 525                    | 519                     | 3.3351                       | 3.0235                        | 0.3116         |
| 3                     | 255          | 510                    | 518                     | 3.7190                       | 3.7428                        | -0.0238        |
| 4                     | 216          | 520                    | 501                     | 2.8608                       | 2.5606                        | 0.3002         |
| 5                     | 217          | 514                    | 506                     | 2.4218                       | 2.3814                        | 0.0404         |

Figure 5 shows the comparison between the original fuel consumption of each segment and the optimized fuel consumption. The total mileage of the ship in the Nanjing-Jingzhou segment is 1323km, original total fuel consumption is 15.3367t, and the optimized total fuel consumption is 14.7135t. The optimized fuel consumption compared with the original fuel consumption, it is reduced by 0.6232t, the original total fuel consumption is reduced by 4.06%.

4. Conclusion

In this paper, based on the navigable environment, divided the voyage into sections, and uses the BP-neural network genetic algorithm function to optimize the maximum value of the main engine speed in the input parameters of the marine diesel engine fuel consumption model.

The results show that: (1) The validation set data is used for verification, and most of the 30 minutes fuel consumption errors do not exceed 6%, indicating that the model has good fitting performance. (2) The use of the segmented optimized main engine speed of the experimental ship on the Nanjing-Jingzhou section of the experimental ship can save 0.6232t of fuel, which is 4.06% lower than the original total fuel consumption.
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