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Real-time optimization of ship energy efficiency based on the prediction technology of working condition

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A B S T R A C T

Ship energy efficiency management and control is an effective strategy to improve the marine economy and reduce CO_2 emission. The determination of the best navigation speed under different working conditions is the basis and premise for real-time improvement of ship energy efficiency. In this paper, the working condition in short distance ahead of the ship related to navigation environment factors was predicted by the method of wavelet neural network, and then the best engine speed for the optimal energy efficiency under different working conditions could be determined through the established ship energy efficiency real-time optimization model. Further, by presetting the ship engine at this optimal speed, the ship energy efficiency could be guaranteed at the optimal state when the ship arrived at the navigation environment ahead of the ship, thus achieving real-time optimization of ship energy efficiency under different navigation environment factors. Experimental studies showed that the proposed optimization model was effective in energy saving and emission reduction, which could provide theoretical guidance for optimal sailing of the ship in service. Compared to traditional setting speed navigation methods, our proposed method has more practical significance to the improvement of ship energy efficiency.

Literature review

In recent years, fuel consumption has accounted for more than 40% of shipping cost, and the high cost exerts serious impact on the healthy development of entire shipping industry. In addition, the environmental problems caused by ship transportation have also attracted more and more attention around the world (Liu, 2006). In view of this, the International Maritime Organization (IMO) has been introducing relevant conventions and improving the standards of ship energy saving and emission reduction continuously (MEPC, 2012). With the growing crisis of global energy and the higher sound of energy conservation and emission reduction, it has become the new challenge for the development of shipping technology to achieve the goals of energy saving and emission reduction through effective ship energy efficiency management measures.

As the IMO proposes, the energy efficiency operation index (EEOI), which is characterized by the amount of CO_2 emission per unit of cargo turnover, can be adopted as the evaluation index of the ship in service. For a long time, the research on

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energy saving of newly-built ships has focused on the application of new energy, the development of energy-saving devices and so on (Hassaine et al., 2014; Eide, 2010). However, for a large number of ships in service, it can save installation cost of the devices and receive immediate repayments through using the operational optimization measures and energy efficiency management strategies to reduce the level of ship energy consumption. Many experts and scholars have studied and proposed various energy saving measures. Hansen and Freund (2010) analyzed the impact of the draft and other factors on the ship's fuel efficiency, and further proposed the ECO-Assistant software by which the crew could monitor the fuel consumption of main and auxiliary in real time. Besides, Ballou et al. (2008) calculated the CO_2 emission reduction based on the method of the voyage and vessel optimization software (VVOS, launched by Jeppesen Marine), and pointed out that the method could significantly reduce the ship fuel consumption by optimizing the route, choosing appropriate speed and taking other measures.

It is noticed that the ship navigation speed has an important effect on both the ship energy efficiency and the ship economy (Norstad et al., 2011). Lindstad et al. (2011) studied the impact of speed reduction on the emission of greenhouse gases and the transportation cost of different kinds of ships worldwide. As was reported, there was much potential for the shipping industry to reduce carbon dioxide emission, and it could achieve about 17% reduction of carbon dioxide emission for RoRo and 14% for bulk ships due to the saving of oil consumption based purely on lower speeds, without increasing the cost measure per million ton Nm. By establishing the maximum benefit model, Corbett et al. (2009) estimated the most economical running speed and the corresponding emission reduction, and discussed the feasibility of reducing the emission through the adjustment of tax rate. Psaraftis and Kontovas (2013) discussed a series of models that took the ship speed as a decision-making variable, and showed that it could improve the ship energy efficiency by optimizing speed. In order to reduce the total annual cost of the ship, Ronen (2011) constructed a cost model and designed a simple computer program to determine the ship sailing speed and the number of ships, and the results showed that the energy efficiency could be improved when the ship ran at the minimum cost speed. Gershanik (2008) and Chang and Wang (2014) pointed out the irrationality of current service speed settings in the contract, and put forward some meaningful speed optimization methods and models to improve the ship energy efficiency. For the inland river ships, Sun et al. (2013) discussed the relationship between the EEOI and the ship speed by calculating and analyzing the EEOI under different working states based on the experimental data, and the results showed that the ship speed had a great impact on the EEOI for inland vessels. In addition, Fan et al. (2015) also studied and analyzed the economical speed of ships and the division of channels on the Yangtze River.

To sum up, the goal of energy saving can be achieved by reducing the sailing speed in a suitable range. However, the best real-time speed of the ship is affected by various factors such as complicated working condition related to the navigation environment factors (Marine Environment Protection Committee, 2009). Hence, the best sailing speed under different working conditions should be determined by comprehensively considering the navigation environment and the sailing states so as to enhance the real-time energy efficiency of ships. Sun (2011) studied the relationship between engine fuel consumption and the environment by regression, and put forward a solving method to improve the energy efficiency of ships. By the neural network method, Yan et al. (2015) conducted sensitivity analysis of the navigation environment factors on the energy efficiency of ships, and demonstrated the correlation between the environmental factors and the ship energy efficiency, which was greatly significant for designing the speed decision-making system and developing new methods to improve the ship energy efficiency. Notably, we should know the navigation environment factors in short distance ahead of the ship in order to maintain the engine running at the optimal speed. By presetting the main engine speed at the optimal speed under that condition, the marine engine can just run at the best speed when the ships arrive at that condition so as to improve the real-time energy efficiency of ships. Therefore, the prediction of the navigation working condition in short distance ahead of the ship is the key to the real-time optimization and control of the ship energy efficiency. Among various prediction methods, wavelet neural network (WNN) has been widely used in scientific research and engineering applications due to its good predictive performance such as strong approximation ability, fast convergence rate and the ability to avoid the local minimum value (Jahedi and Ardehali, 2012; Raza and Khosravi, 2015). Prahlada and Deka (2015) forecast the time series of significant wave height using the wavelet decomposed neural network and had achieved good predictions. Chitsaz et al. (2015) focused on the wind power forecast using the same method, and confirmed the validity of the developed approach. In this paper, WNN was used for the prediction of the navigation working condition. On the basis, the feasible real-time optimization method of ship energy efficiency was built through the establishment of the ship energy efficiency real-time optimization model. Besides, energy efficiency design index (EEDI) is a criterion to judge CO_2 emission for a designed ship (MEPC.l/Circ.681, 2009). There are some strategies to reduce EEDI, such as improving fuel economy (Ančić and Šestan, 2015), using environmentally friendly energy (Ekanem Attah and Bucknall, 2015) and so on. Among these new technologies and new methods, it may be a direct and effective method to meet the requirement of EEDI by reducing the speed and the installed power of main engine according to our results.

The rest of this paper is organized as follows. The second section describes the wavelet neural network used for the prediction of navigation environment parameters, including the wind speed, the water depth and so on. Then, data collection is carried out in the third section. The fourth section describes the prediction results of navigation environment parameters based on the wavelet neural network. Further, the real-time optimization model and control method for energy efficiency are established in the fifth section. On this basis, case study is conducted to verify the established model in the sixth section. Finally, the seventh section summarizes and concludes the paper.