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Prediction of added resistance using genetic programming

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ABSTRACT

In recent years, the increasing demand for a reduction of carbon emission has made hydrodynamic design and the optimization of hull design more important. For appropriate hydrodynamic design, the added resistance needs to be predicted. However, as existing methods including computer simulations or experiments require considerable amounts of time and money, it is difficult to consider the prediction result at the initial design stage. Therefore, in this paper, we propose a prediction method that can be used in the initial design stage for predicting the added resistance in waves, thereby contributing to the optimization of hull design and saving time and money. The proposed method is a nonlinear mathematical function and is based on genetic programming. For verification, the predicted results are compared with the experimental results and the strip theory results.

1. Introduction

In recent decades, people have become increasingly aware of the need for environmental protection, and one of the most important environmental issues considered today is global warming. Although there are several factors that cause global warming, carbon emission is considered the most powerful trigger. Therefore, many countries and industries are striving to reduce carbon emissions by using new methods, materials, and regulations. From this perspective, the International Maritime Organization suggested that all ships manufactured since 2013 meet the energy efficiency design index requirement to alleviate carbon emission. Further, currently, Industry 4.0 is trending globally, which implies that the industry is attempting to maximize the use of automation and connectivity. Maximized automation and connectivity are achieved by using the Internet of things (IoT) and artificial intelligence (AI). A prominent characteristic of AI is that it collects and analyzes data from various sources and then makes decisions on its own. Since the advent of Industry 4.0, many researchers have attempted to apply IoT and AI to their industries. Consequently, the shipbuilding industry's interest in improving operational efficiency by using IoT and AI has increased.

To increase operational efficiency, the hull form needs to be optimized by considering the added resistance, which is a part of a ship's total resistance caused by incident waves, because a ship is likely to experience 10%–30% more resistance in a seaway than in a calm sea because of such added resistance (Péres, 2006). In traditional methods, the optimization of ship geometry does not consider the effects of the wind and the waves, although it considers speed, trim, and draft under calm weather. Therefore, we need to take into account the effects of waves for optimizing ship geometry by predicting the added resistance. Furthermore, traditional methods yield suboptimal performance because they optimize the ship hull by considering design conditions such as the specified speed, trim, and draft and calm weather (i.e., without wind and waves). However, in real life, most vessels operate during windy weather and are affected by waves. Therefore, the potential suboptimal performance of these methods leads to economic losses, and considering outdoor design specifications would be advantageous (Gonzalo, 2011). However, as the traditional methods of calculating the added resistance require considerable amounts of time, money, and manpower, it is difficult to consider the added resistance in the initial design stage. Therefore, in this paper, to consider the added resistance in the initial design stage, an alternative method of predicting the added resistance is proposed by using a genetic programming (GP) system developed with a commercial software program (MATLAB). Methods using GP require less money and time than conventional methods because the use of GP merely exploits the certified data of similar ships, which can be obtained from experiments or widely used equations, to estimate the added resistance instead of using experiments or calculating functions that require considerable amounts of money and time.

The proposed method consists of an approximate nonlinear mathematical function and the GP results. To the best of our knowledge, few studies using GP as a key technique have focused on the prediction of the added resistance. Therefore, in this study, we investigate the

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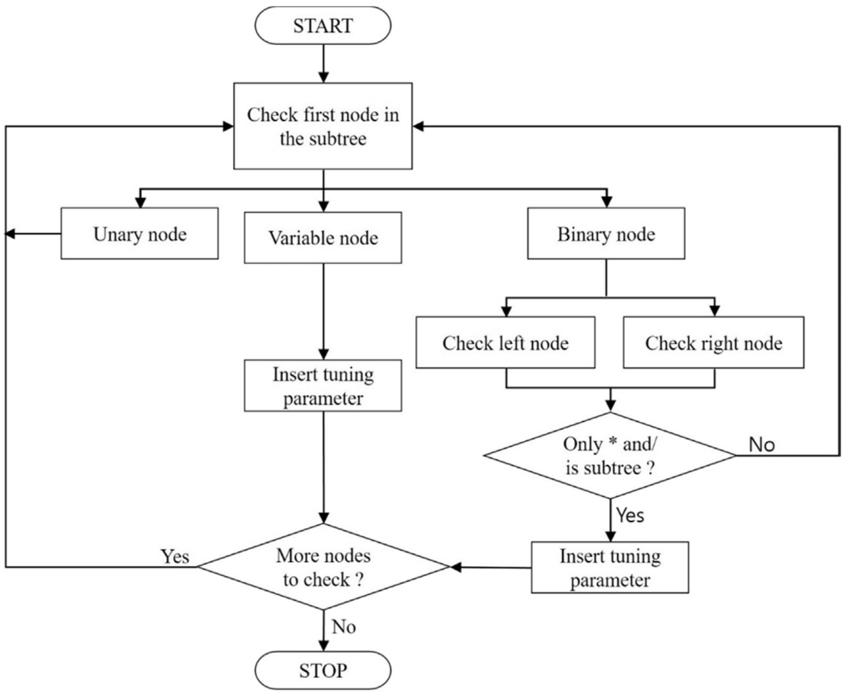

Fig. 1. Flowchart for genetic programming (GP).

applicability of GP to the added resistance prediction. Further, to verify the accuracy of the predicted results, these results are compared with the experimental data and the strip theory data.

The rest of this paper is organized as follows. In Section 2, the concept of added resistance, the general methods used for predicting this resistance, and the methods considered in this study are introduced. As the focus of this study is GP, GP's basic theory and its application in similar cases are explained in Section 3. Section 4 describes the proposed method, the test ship's parameters, the GP process and parameters, and the validation of the proposed method. Finally, Section 5 presents the conclusion.

2. Added resistance in waves

The ocean almost always has windy weather and waves, and these inevitably trigger more resistance than that expected during calm weather, which is usually assumed for the optimization of hull design; this difference in resistance is called the added resistance. Therefore, predicting the added resistance improves the accuracy of a ship's total resistance prediction, thereby helping to optimize the ship hull design.

Further, the prediction of the added resistance is used for solving certain problems related to the weather margin, weather routing, and performance analysis (Alexandersson, 2009), as the calculation of the weather margin and weather routing requires the total resistance of a ship and the added resistance prediction increases the accuracy of the total resistance prediction. In particular, it is important and profitable for ship owners to optimize travel routes because this results in lower operational costs. On the other hand, performance analysis deals with the prediction of the added resistance as a measurement of a ship's performance. For example, Tsujimoto et al. (2008) and Ichinose et al. (2012) studied the added resistance to estimate the decrease in ship speed in actual seas.

2.1. Methods to calculate added resistance in waves

Thus far, some methods have been developed to predict the added resistance in waves; these methods can be divided into two main categories: far-field and near-field methods. The far-field method takes into account diffracted and radiated wave energy and momentum flux at infinity to predict the added resistance and then calculates the steady added resistive force using the change rate of momentum. In contrast, in the case of the near-field method, the added resistance is obtained as a steady second-order force. The near-field method integrates the hydrodynamic force and the steady second-order force acting on the wetted ship surface. The far-field and near-field methods were first introduced in the 1950s by Maruo (1957) and in the 1970s by Boese (1970), respectively. Since then, these methods have been considerably improved by several researchers. Some examples of these improved methods are Gerritsma and Beukelman's method (Gerritsma and Beukelman, 1972), Boese's method, and Faltinsen's asymptotic method (Faltinsen et al., 1980). Gerritsma and Beukelman's method, which is called the radiated energy method, calculates the added resistance by determining the radiated energy of the damping waves. As it assumes a constant forward ship speed, the surge motion is neglected, but the heave and pitch motion is calculated using the strip theory. Boese's method, which is called the pressure integration method, integrates the total linear pressure over the ship hull under calm wave conditions to obtain the mean force in the heading direction of a ship. These two methods are implemented to deal with radiation-induced resistance, whereas Faltinsen's asymptotic method is used in cases of diffraction-induced resistance and a lack of ship motion. The added resistance is usually predicted by using these methods with computer programs or experimental methods. However, these processes, which use computer programs such as computational fluid dynamics (CFD) simulations and model experiments, have certain disadvantages. In particular, both the simulations and the experiments require considerable amounts of time, money, and manpower. Further, although these methods consider many alternative design cases, the prediction results of the CFD simulations or the experiments always have a few errors. In other words, it is difficult to apply the prediction results to the initial design stage. Therefore, a new method that consumes less time and money to predict the added resistance is required to consider a hydrodynamic design in the initial design stage.

3. Genetic programming (GP)

As mentioned in Section 1, AI has recently attracted considerable