Real-time deterministic prediction of ship roll motion based on time series

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ABSTRACT

Real-time deterministic prediction of ship roll motion in the next few seconds is crucial in decision making to perform actions and sensitive activities. The difficulty in ship motion prediction is that ship motion has non-linear and non-stationary characteristics. Time series analysis theory considers that relations are existing among variables of the time sequence, therefore, present variable is able to be represented by the previous in time. The purpose of this paper is to find a model with high accuracy and applicability for the future ship roll motion prediction. Therefore, four ship motion prediction models: autoregressive model (AR), empirical mode decomposition-autoregressive (EMD-AR), long short-term memory network (LSTM) and EMD-LSTM model are investigated in detail. The experiments of a practical ship are carried out in Bohai Sea, China, to demonstrate the reliability and practicability of the four methods. Numerical results show that the basic prediction function can be obtained through the AR, EMD-AR, LSTM and EMD-LSTM model for the small prediction lead steps. For large prediction lead steps, the error of the EMD-LSTM model is lower than that of other models. It has been proved that the EMD-LSTM model has good performance in different datasets and different prediction lead steps, showing good superiority and applicability, which provides a potential method for ship roll motion prediction.

KEY WORDS: Ship motion prediction, EMD algorithm, AR model, LSTM model, prediction lead step.

INTRODUCTION

Many research works have been conducted on ship motion predictions. A large proportion of such researches are focused on ship roll motion, since it is the most important motion in relation to ship stability and navigation safety. In harsh sea conditions, strong nonlinear roll motion will cause great harm to the navigation safety and control of ships. Such as, the fierce collision between carrier aircraft and flight deck, the difficulty of helicopter parking, the failure of radar tracking and locking target, the seasickness of sailors and etc. The real-time prediction of ship roll motion in future seconds is used to improve operational safety and efficiency, and it is crucial in decision making to perform actions and sensitive activities (Wei et al., 2022).

However, the ship roll motion is difficult to predict, since it is a complex nonlinear system with time-varying dynamics. The autoregressive (AR) model is one of the most explored models due to its simplicity and practicability (Jiang et al., 2020). It uses past time series data for statistical analysis to predict future trends. When lead time is short (1s~2s), AR model gives good predictions, but it fails to capture the amplitude of the target ship motion when lead time exceeds 5s. The AR models are generally developed based on linear and stationary theories and hence suffer difficulties in nonlinear and non-stationary ship motions modeling.

To handle ship motion nonlinearity, various models based on the nonlinear time series and artificial intelligent theories were proposed. For example, artificial neural network (ANN), support vector regression (SVR) (Hou and Zou, 2015), radial basis function (RBF) (Yin et al., 2013; Yin et al., 2018), reservoir computing (RC), recurrent neural network (RNN) and etc. It has been widely explored to solve various nonlinear time series problems, such as stock market prediction, electricity forecasting (Chi, 2022), weather prediction (Salman et al., 2018), mechanical remaining life (Chang et al., 2022; Xia et al., 2021) and etc. Long short-term memory network (LSTM) is a memory model in deep learning, which has strong nonlinear fitting ability and time memory function. The LSTM model has a good performance in ship motion prediction (Liu et al., 2020; Sun et al., 2022; Zhang et al., 2021). However, the optimization of LSTM model is very difficult, since its loss function is non-convex function, which is difficult to find the global optimal solution. In practical applications, there will be problems such as poor model adaptability, single prediction results, and unsatisfactory prediction accuracy.

Compared with the nonlinearity problem, non-stationary processing is more challenging. Empirical mode decomposition (EMD) proved to be the most capable in non-stationary processing. EMD-based hybrid models were widely explored in nonlinear and non-stationary real-time ship motion forecasting. Nie et al confirms the negative EMD boundary effect on the prediction accuracy of classical EMD-SVR model and validity of the mirror symmetry method using the rolling and pitching of ship motion data collected during sailing for experiments (Nie et al., 2020). Hao et al combines the advantages of the LSTM model and EMD and proposes an EMD-LSTM method. It has been found that the EMD-