



# Measures to diminish the parameter drift in the modeling of ship manoeuvring using system identification



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## ABSTRACT

System identification provides an effective way to predict the ship manoeuvrability. In this paper several measures are proposed to diminish the parameter drift in the parametric identification of ship manoeuvring models. The drift of linear hydrodynamic coefficients can be accounted for from the point of view of dynamic cancellation, while the drift of nonlinear hydrodynamic coefficients is explained from the point of view of regression analysis. To diminish the parameter drift, reconstruction of the samples and modification of the mathematical model of ship manoeuvring motion are carried out. Difference method and the method of additional excitation are proposed to reconstruct the samples. Using correlation analysis, the structure of a manoeuvring model is simplified. Combined with the measures proposed, support vector machines based identification is employed to determine the hydrodynamic coefficients in a modified Abkowitz model. Experimental data from the free-running model tests of a KVLCC2 ship are analyzed and the hydrodynamic coefficients are identified. Based on the regressive model, simulation of manoeuvres is conducted. Comparison between the simulation results and the experimental results demonstrates the validity of the proposed measures.

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## 1. Introduction

Ship manoeuvrability is one of the most important ship hydrodynamic performances. Prediction of ship manoeuvrability at the design stage has been recommended in the Standards for Ship Manoeuvrability by the International Maritime Organization (IMO) [1]. During the last decade, research on the prediction of ship manoeuvrability has been increasingly paid attention to. Generally, two ways, simulation-free and simulation-based methods, can be used to evaluate the ship manoeuvring performances like advance, transfer, tactical diameter, overshoot angles, time to check yaw [2]. Simulation-free method is a direct method since one can obtain the manoeuvrability parameters directly from database, full-scale trials or free-running model tests. For the simulation-based method, the manoeuvring performances are predicted by means of computer simulation. Compared with simulation-free method, the simulation-based method is preferred in the prediction of ship manoeuvrability due to the development of computer science and techniques. To perform manoeuvring simulation, a

ship manoeuvring model is indispensable and the accuracy of the model determines the prediction accuracy. Commonly used ship manoeuvring models include Abkowitz model [3], MMG model [4], and response model [5]. Abkowitz model and MMG model can also be called as hydrodynamic models. No matter which model is employed to predict ship manoeuvring, it is required to determine the model parameters first. For Abkowitz model and MMG model, those parameters are referred to as hydrodynamic derivatives (coefficients) while manoeuvring indices for response model. Although the response model presents a simpler manoeuvring model in which fairly few parameters are contained, in the ship manoeuvrability community an Abkowitz model or a MMG model is usually preferred because they provide a more comprehensive description of ship manoeuvring motion. Nevertheless, it is challenging to accurately determine so many hydrodynamic coefficients in a hydrodynamic model.

Five methods are available to determine the hydrodynamic coefficients in a mathematical model of ship manoeuvring, including database, empirical formula, captive model test, CFD calculation and system identification (SI). Among these, the SI based method provides an effective and practical way. Its main advantages refer to (i) combined with free-running model tests, the cost is relatively low since it is easy to generate more manoeuvres after a first set of model tests; (ii) this method can be applied to either

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model-scale or full-scale manoeuvres [2]. When applied to full-scale trials, the scale effect can be avoided. During last decades, the SI application to the modeling of ship manoeuvring has been continuously studied and many SI schemes have been proposed to derive hydrodynamic coefficients, including least squares (LS) [6,7], model reference method (MRM) [8,9], extend Kalman filter (EKF) [10,11], maximum likelihood (ML) [12,13], recursive prediction error (RPE) [14,15], frequency spectrum analysis (FSA) [16,17], particle swarm optimization (PSO) [18,19], genetic algorithm (GA) [20,21], neural networks (NN) [22,23], and support vector machines (SVM) [24,25]. During the past decade, with the development of experimental and identification techniques, SI based modeling of ship manoeuvring has received increasing attention.

As pointed out, each means to come to manoeuvring predictions has its own advantages and disadvantages [2]. For SI based method, the main difficulty is how to deal with the problem of parameter identifiability. Such an issue can be described from two aspects. First, not all parameters in the manoeuvring model can be obtained using SI, no matter what input–output samples are given and no matter which SI scheme is adopted. Second, parameter drift happens to some hydrodynamic coefficients, which means the obtained coefficients deviate from their true values. For the first kind of parameter identifiability, an effective solution is to determine some hydrodynamic coefficients first in another way instead of SI, such as the slender-body theory, empirical formula, captive model test, or CFD calculation. Afterwards, the remaining hydrodynamic coefficients can be obtained using SI. Usually but not always, the inertia hydrodynamic coefficients, i.e. added masses and added moments of inertia, are selected to be predetermined and satisfactory estimation can be obtained [26–30]. For the second kind of parameter identifiability caused by parameter drift, it is more complicated and challenging. When parameter drift happens, one might obtain a ‘deceptive’ regressive model. This model can predict some manoeuvre well while fails for the other manoeuvres. The effect of parameter drift nearly always exists when applying SI to derive a ship manoeuvring model. Moreover, this effect is more severe for the identification of a complicated model for instance the Abkowitz model.

To diminish the parameter drift, some measures have been proposed such as parallel processing, exaggerated over- and under-estimation, parameter transformation [10,31,32], modification of input scenario [13,33,34], and model simplification by sensitivity analysis [35–37]. Nevertheless, more attention should have been paid to this topic to develop the SI based prediction of ship manoeuvrability. In addition, some issues are supposed to be further addressed, for example the diminishment of drift of nonlinear hydrodynamic coefficients, design of the excitation, the criteria adopted in sensitivity analysis. In this paper, those issues are addressed. Efforts are devoted to the diminishment of the drift of linear and nonlinear hydrodynamic coefficients in an Abkowitz model. The reasons for parameter drift are accounted for. Several measures to diminish the parameter drift are presented, including two measures to reconstruct the data samples, and a measure to modify the mathematical model of ship manoeuvring motion as well. Combined with the diminishment measures, SVM based SI is employed to obtain the hydrodynamic coefficients. The training samples are taken from the free-running model tests of a KVLCC2 ship. Manoeuvring simulation is performed based on the identified hydrodynamic coefficients. Comparisons between the predicted results and experimental results demonstrate the validity of the measures proposed.

The rest of the paper is organized as follows. In Section 2, the reasons for the drift of linear and nonlinear hydrodynamic coefficients are accounted for. In Section 3, three measures are presented to diminish the parameter drift. In Section 4, manoeuvring simulations are performed and comparison results are

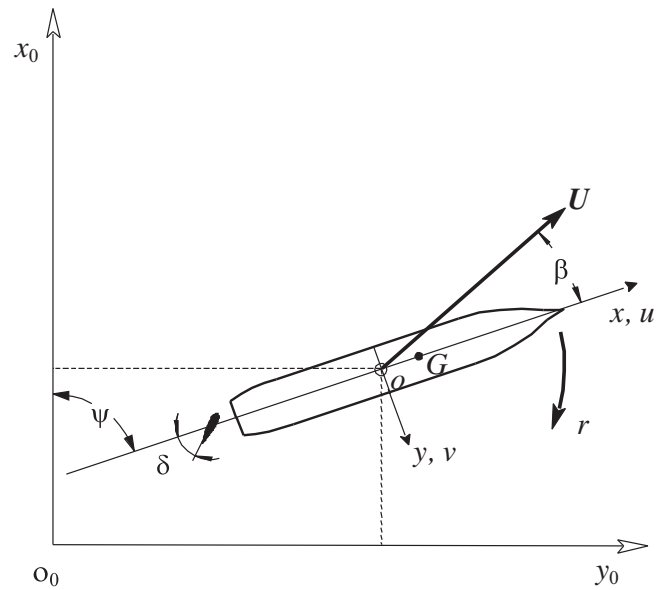


Fig. 1. Coordinate system of ship manoeuvring motion.

presented. SVM approach is also described. The final section is conclusion.

## 2. Parameter drift of hydrodynamic coefficients

When parameter drift happens to hydrodynamic coefficients, the obtained coefficients deviate from their true values. These parameters might be physically incorrect but mathematically correct. This phenomenon can be explained by an example. Using 10°/10° zigzag manoeuvre test data, one can identify the hydrodynamic coefficients in a hydrodynamic model (e.g. Abkowitz model). The obtained manoeuvring model might be able to predict the same manoeuvre (i.e. 10°/10° zigzag manoeuvre) well when manoeuvring simulation is performed. However, for other manoeuvres such as 20°/20° zigzag manoeuvre, the obtained model fails to predict. In a worse case, such a ‘mathematically correct’ identification even cannot happen.

The reason for the drift of linear hydrodynamic coefficients can be explained from the point of view of mechanics. Hwang [31] and Clarke et al. [38] applied the slender-body theory to calculate the linear force and moment in the ship manoeuvring motion. It was found that dynamic cancellation happened and resulted in the simultaneous drift of linear hydrodynamic coefficients. Different from the linear hydrodynamic coefficients, it is difficult to obtain theoretical calculation for nonlinear hydrodynamic coefficients. As a result, the reason for the drift of nonlinear hydrodynamic coefficients cannot be explained physically. Nevertheless, it can be explained from another point of view, i.e., statistically. By means of regression analysis, it can be concluded that the drift of nonlinear hydrodynamic coefficients results from the so-called multicollinearity.

### 2.1. Simultaneous drift of linear hydrodynamic coefficients

The motion of a ship can be described in a six-degree-of-freedom frame. In detail, the motion concerns surge, sway, yaw, heave, pitch, and roll. From the point of view of prediction of manoeuvring, attention is often paid to the ship motion in the horizontal plane instead of the vertical plane. In other words, only surge, sway and yaw are taken into account. Fig. 1 depicts the ship manoeuvring motion. The inertial coordinate system is denoted by  $x_0y_0$ ,  $xoy$  is the attached coordinate system,  $G$  is the center of gravity,  $u$  is the surge speed,

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