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Validation of ship manoeuvring models using metamodels

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ABSTRACT

This paper describes how simplified auxiliary models—metamodels—can be used to create benchmarks for validating ship manoeuvring simulation models. A metamodel represents ship performance for a limited range of parameters, such as rudder angles and surge velocity. In contrast to traditional system identification methods, metamodels are identified from multiple trial recordings, each containing data on the ship's inherent dynamics (similar for all trials) and random disturbances such as environmental effects and slightly different loading conditions. Thus, metamodels can be used to obtain these essential data, where simple averaging is not possible. In addition, metamodels are used to represent a ship's behaviour and not to obtain physical insights into ship dynamics. The experimental trials used for the identification of metamodels can be found in in-service recorded data. After the metamodel is identified, it is used to simulate trials without substantial deviations from the ship state parameters used for the identification. Subsequently, the predictions of the metamodels are compared with the predictions of a tested manoeuvring simulation model. We present two case studies to demonstrate the application of metamodels for moderate turning motions of two ships.

1. Introduction

Validating ship manoeuvring models used for training pilots and in engineering applications is important [1,2]. Despite the increasing use of simulation models, no standards or guidelines describing an objective validation method of system-based manoeuvring models are currently available. In the majority of relevant literature, manoeuvring models are typically validated for application in standard International Maritime Organization (IMO) trials [3], including turning circles and zigzag trials, for example, [4]. These trials are executed at nearly full speed and are intended to assess the emergency turning and course checking abilities of a ship. However, for other applications, such as training pilots to steer a ship in port areas, trials such as low-speed turning with the assistance of tunnel thrusters, would be more realistic. Thus, as was the conclusion of a review of the guidelines for validating aviation simulators [5], manoeuvring models should be validated for a wider range of ship-specific applications.

High-quality benchmark data are necessary for validation. Such data can be obtained through dedicated tests, such as [6]. However, such tests are cost prohibitive. An alternative approach is to use in-service recorded data and to validate a simulator against the motions recorded during real ship operation. However, in-service data are affected by numerous sources of uncertainty, such as environmental effects and difference in loading conditions. Moreover, limited data may be available; for example, for validating an emergency turning model, it is unlikely that such a record would be found in in-service recorded data. Therefore, validation against in-service data should be considered a complimentary approach to validation against the results of dedicated trials.

Data from in-service measurements tend to have larger uncertainty than do data from dedicated trials. Nevertheless, because of the long-term nature of data from in-service measurements (e.g., data from a year of operation), the uncertainty in the validation dataset may be reduced by utilizing the 'repeated tests' effect of the in-service data. In this paper, we use auxiliary simplified mathematical models (metamodels) for validation. Metamodels are widely used in many domains, such as systems analysis and software engineering, and typically represent the model of a model or the model of a particular phenomenon, keeping only critical features. Metamodels are identified from similar trials of a real ship and are then used as a benchmark for simulations. Thus, the identified metamodel is a manoeuvring model valid for a particular manoeuver. This approach minimizes uncertainty and can be considered as 'smart averaging' for that manoeuvre. The rest of this paper is organized as follows. In Section 2, we briefly describe the concept of a metamodel and its application. In Section 3, we present

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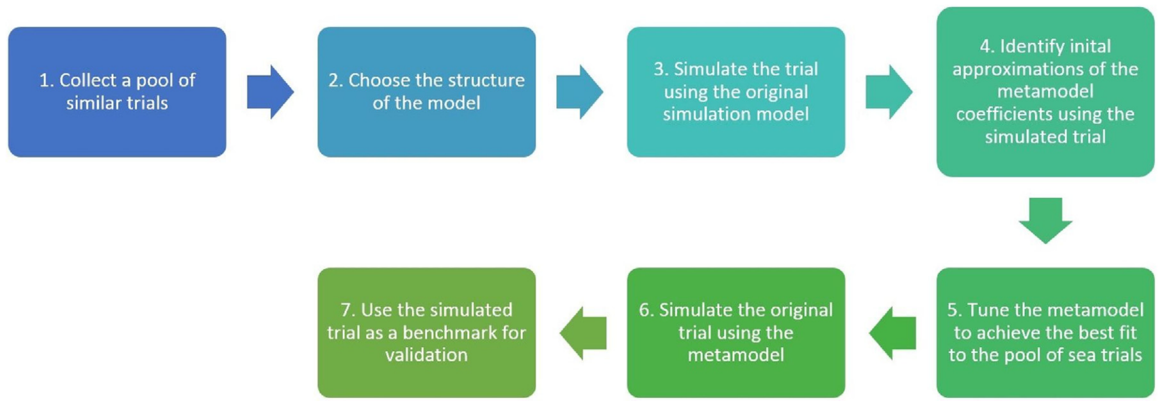

Fig. 1. Validation process using metamodels.

two case studies using the in-service data of coastal ferry Landegode and the zigzag trials of Research Vessel Gunnerus. Finally, the conclusions are presented in Section 4.

2. Metamodels and validation

System identification is widely applied in ship manoeuvring to obtain coefficients in simulation models. In [7], Abkowitz applied the extended Kalman filter to identify model coefficients and changing current from the tests of vessel Esso Osaka. Abkowitz noted that the identified coefficients could be used for validating an original mathematical model, but he did not report such a validation nor did he present instructions to perform such a validation.

The approach presented in this paper relies on system identification. Fig. 1 delineates the approach in a stepwise manner. Steps 3 and 4 can be skipped for simple metamodels, but it may be essential for complex models. In Step 5, known environmental effects, such as mean drift due to current and waves identified for each individual trial, can be accounted for. The key distinctions of metamodel identification from traditional manoeuvring model identification are as follows:

- The structure of a metamodel can differ from the structure of the model that is validated. Different metamodel structures can be used in trials with different objectives.
- Several similar trials are used to identify a metamodel. Thus, the influence of random components due to environmental conditions and other disturbances is minimized by averaging.

Thus, a metamodel represents the averaged response of a ship to certain control inputs.

3. Case study

3.1. Manoeuvring models

Two case studies are presented. In the first case study, metamodels are used to generate benchmark trials on the basis of in-service recorded data, and in the second, multiple repetitions of zigzag trials are used. In each case, after the metamodel is identified, we demonstrate the validation of the original manoeuvring models by using VeSim simulation models. VeSim, developed by the Norwegian Marine Technology Research Institute (MARINTEK), is an advanced six-degrees-of-freedom simulator based on unified manoeuvring and seakeeping theory [8]. A modular approach is implemented in the simulator. Because the validation of these particular models is not the primary objective of this study, the models are only briefly described in this paper.

Fig. 2. Ferry Landegode.

Table 1
Main dimensions of ferry Landegode.

Length overall [m]	96.0
Breadth midship [m]	16.8
Draught (max) [m]	4.2

3.2. Case study 1: ferry Landegode

In this case study, we apply metamodels to create a validation benchmark by using in-service recorded data from ferry Landegode (Fig. 2). The ferry operates on routes near Bodø in Northern Norway and is one of the case vessels used in the research project 'SimVal—Sea Trials and Model Tests for Validation of Shiphandling Simulation Models' [9].

Table 1 shows main dimensions of the ferry. The ferry is equipped with a single-screw single-rudder propulsion system with a controllable pitch propeller and three tunnel thrusters, two in the bow and one in the stern.

3.2.1. Searching manoeuvres in recorded data

During operation, all main parameters, such as positions, orientation, velocities, propulsion parameters, wind direction, and velocity, are recorded and stored as 1-h-long time series with short 30-s-long intervals in between. Most recorded data pertain to nearly straight motion and are not relevant for manoeuvring tests. Therefore, the first task is to identify sections of the time series representing turning motion, as follows:

Step 1. Data cleaning and preparation: All data is low-pass filtered and resampled using spline interpolation to the same sampling frequency. A simple data check is performed to exclude faulty