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► **To cite this version:**

Moritz Von Stietencron, Shantanoo Desai, Klaus-Dieter Thoben. Virtualization of Sea Trials for Smart Prototype Testing. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2019, Austin, TX, United States. pp.365-371, 10.1007/978-3-030-29996-5_42 . hal-02460490

HAL Id: hal-02460490

<https://inria.hal.science/hal-02460490v1>

Submitted on 30 Jan 2020

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Virtualization of Sea Trials for Smart Prototype Testing

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Abstract. The design and development of new vessels is a cost and time-intensive effort, which is greatly reliant on expertise and experience. The prototype building and testing are, especially for small producers who do not sell on volume, often at the same time the production of the first vessel. This further increases the need for other means of reliable and accurate prototype experimentation. This paper presents a procedure for the virtualization of sea trials in which the vessel prototypes are tested, thus generating a concise and reliable data model of the trial, which can be used in simulation and other product development tasks.

Keywords: IoT, Knowledge-based Engineering, Vessel Design, CFD.

1 Introduction

The landscape of European producers of specialized boats, like emergency response and recovery vessels (ERRV), is marked by small and medium enterprises, which manufacture these vessels on a made-to-order basis. With regards to the product design and development stage, this adds further restraints to the fact, that the total volumes of these vessels are rather small (with the German DGzRS currently employing 39 [1] and the Norwegian RS 51 [2] small rescue vessels). With these constraints and the fact that these vessels are financed through donations, there is a significant emphasis on the development phase of the vessels as the margin for building separate prototypes is usually not available. At the same time, of course, there are particularly high standards and requirements [3] attached to each order, as a lot is at stake during search and rescue missions.

The majority of manufacturers already utilize computer-based prototype testing and development methods, e.g., through simulations. However, the output of these measures can only be granted a limited amount of credibility as it vastly relies on assumptions, e.g., about the driving conditions and the corresponding vessel behavior. Often these assumptions are complemented with extensive experience of the involved vessel designers and naval engineers. Still, in the pursuit of reducing uncertainty about the products real-world behavior, real-world sea trials are the state of the art means of product experimentation. While the vessel stability is usually rather well understood by the developers and is the main objective of the testing procedures, an increasing focus

is given to the effects of the boat's performance on the personnel and the environment [4].

The extended usage of the digital development aids is seen as a necessary direction in the production of these vessels but currently faces some challenges which obstruct the implementation of entirely virtual sea trials, of which the reliability of the underlying information is a crucial factor.

This paper presents an approach, to eliminate some of the uncertainty in the process of running virtual sea trials by presenting an approach to digitize real-world sea trials and offer a pathway to the usage of virtual sea trials in a fact-based vessel design process.

2 Related Work

Across the range of usage of small vessels, the usage patterns vary significantly, which results in a high level of ambiguity in the design process, which this paper proposes to reduce by introducing a higher level of real-world product behavior into the development process. This chapter briefly introduces the two main concepts behind this, namely knowledge-based vessel development and marine sensor data acquisition.

2.1 Knowledge-Based Vessel Development

It is necessary to compress development cycles [5] to optimize the vessel development process towards high-quality products without compromising the financial feasibility of the developments. In recent years, concepts like concurrent engineering [6] have been applied to the domain of vessel development [7]. These advances are complemented by investigations on the integration of product behavior knowledge into a product development process [8, 9]. Together this has led to the implementation of a modeling language for knowledge-based engineering tasks called KbeML (knowledge-based engineering modeling language) in the vessel design process [10]. This process is highly dependent on a reliable stream of vessel-related sensor data.

2.2 Sensor Data Acquisition

Modern vessels contain a large number of sensors within them, depending upon the requirements of the users as well as the vessel designers. These sensors tend to communicate with the vessel's subsystem through standardized protocols developed by the National Marine Electronics Association (NMEA). Two of the well-known standards within the maritime sector are NMEA0183 and NMEA2000. NMEA0183 uses the RS422 Serial interface, while the NMEA2000 uses the modern Computer Area Network (CAN) interface and provides higher speeds compared to NMEA0183 [11].

For modern IoT applications, these protocols produce crucial challenges. Since the data is only available on the local network of the vessel and for simple applications, obtaining information from these networks and sending them to cloud-based infrastruc-

ture pose as a critical challenge. Since operating vessels are more often at sea, the information exchange between the vessel and the cloud services becomes a vital task to execute. While there are several commercial systems available to monitor either variables at a global level on the vessel or highly specialized data sets for single development questions [12] only a few approaches feature the flexibility and capability needed to make such a system appealing to small and medium vessel producers. Some efforts are currently being made by open-source communities to bridge the gap between bringing such vital information from vessels to cloud infrastructure where it can be analyzed and fed back to the production aspect for better and optimal vessel design. One such open-source project is Signal K [13] as well as the Universal Marine Gateway (UMG).

Subsequently, we describe an overview of Signal K as well as the Universal Marine Gateway (UMG) which provide different approaches to acquiring sensor data from vessels.

Signal K. Signal K is an open-source solution, driven by a community of sailing and marine enthusiasts. It strives to achieve an open data format for the maritime sector by using standard internet technologies on the vessel using a dedicated Signal K server. The complete solution is licensed under Apache v2.0 permissive open-source license. A significant advantage that the project accomplishes is the representation of the data from various heterogeneous sources of information. It is easily deployable on a standard laptop as well as different single-board computers (SBCs) and relies on standard internet technologies like REST, WebSocket, and TCP/IP suite for information exchange [14]. The data format within Signal K is represented using JSON Schema with UTF-8 encoding, making it compatible with many standard IoT solutions.

UMG. The Universal Marine Gateway (UMG) is a data acquisition unit capable of interfacing various data busses as well as different sensors and has been developed through a series of collaborative research projects. At its hardware core is an industrial-grade single board computer with a customized operating system. The UMG hosts a time-series database, which stores the vessel data and allows for data curation. While the Signal K framework is more addressed towards the requirements of the consumer market, the UMG is an implementation for professional users. It comprises of a subsystem of UMG Nodes which handle data from various heterogeneous data-sources (e.g., data buses and digital or analog sensors) and sends it to the UMG through an ethernet network deployed within the vessel. UMG Nodes provide deployment opportunities to place different sensors like accelerometers within the vessel at locations normally difficult to access like the hull or engine room.

3 Approach

The basis for a virtual sea trial is usually a computational fluid dynamics (CFD) simulation of the vessel model in relevant simulation space. Besides a well-defined vessel model, the data basis for this simulation is the crucial step towards running a credible virtual sea trial. This paper's approach is, therefore, to employ a flexible data acquisition system to capture a precise model of a sea trials parameters and deliver reliable data which can remove ambiguity from the current digital design process.

3.1 Virtualization Prerequisites

It is crucial to work from a concise set of requirements and expectations to create a meaningful model of a sea trial. Therefore, the first step in the virtualization process is to define these. It is essential to define the scope of the digitization. In general, the following three data scopes are differentiated:

1. Data describing the environmental input to the trial situation (e.g., wind speed, wave height)
2. Data describing the vessel's input to the trial situation (e.g., engine speed, heading)
3. Data describing the vessel's behavior in the trial situation (e.g., deformation, accelerations)

Once the scope has been decided for the sea trial at hand, the individual measurements and their parameters need to be defined. The process will involve the selection of data sources (e.g., sensors, onboard systems) as well as their type of placement and calibration parameters.

3.2 Sea Trial Virtualization

With the data acquisition parameters finalized, the second step is the virtualization of a real-world sea trial. Besides the configuration of the data acquisition system to the requirements fixated in the first step, the mode of installation on the vessel must be prepared before the sea trial. Most important factors are the exact placement and fixation of the sensors as it is especially crucial for sensors which track physical variables, like vibration.

Before the actual sea trial occurs, the behavior of the vessel in the zero state condition shall be captured which implies to store data from all sensors with minimal environmental influence to capture the impact of the vessel itself on the readings and establish a baseline for measurements during the sea trial. It is recommended to do this for 15 minutes with the engine turned off and another 15 minutes with the engine at idle speed.

It is vital to ensure proper synchronization of the system time to allow the correlation of the data from the vessel with external data sources (e.g., weather service), and it is highly recommended to do this before the sea trial. During the sea trial, the live data can be monitored in real-time on the vessel or with minimal delay on an accompanying vessel or shore station.

After the end of the sea trial, it is recommended to repeat the zero state capturing procedure to document whether and if so, how the sea trial has impacted the installation.

3.3 Data Curation

After the sea trial, data curation is recommended and should consist of the following steps. First, the data validity needs to be checked. Besides quantitative consistency checks (e.g., on the required and real sampling frequency) also qualitative verifications

(e.g., comparison of pre and post sea trial zero state conditions) shall be performed to ensure a high level of data quality. Subsequently, the data shall be annotated with events (e.g., time of a specific maneuver) and subjective findings (e.g., uncomfortable driving situation) from the sea trial. Finally, the data should be persisted both in a database for further use in analysis and simulation as well as in a report to summarise the sea trial.

4 Validation

For the validation of the sea trial virtualization procedure, an ongoing vessel development process of the Norwegian boat manufacturer Hydrolift¹ has been selected. With the development of highly modular vessel platform, the sea trial virtualization experimented. Fig. 1 below gives an overview of the stages of the validation experiment.

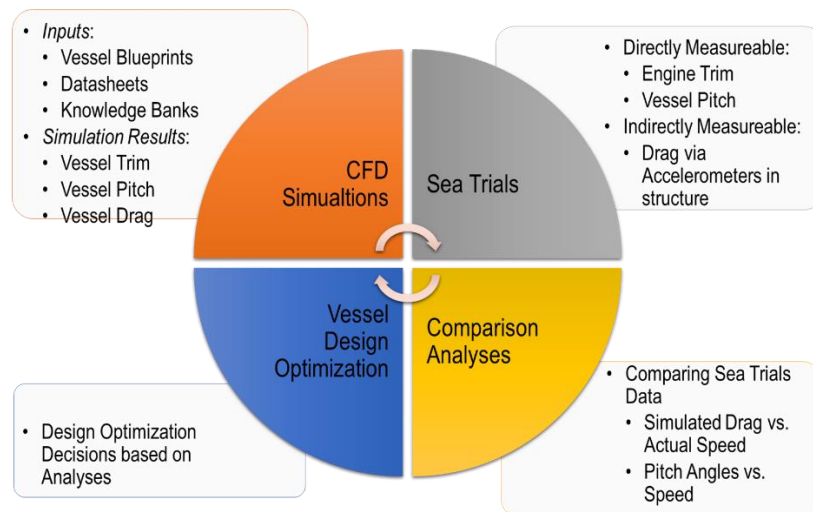


Fig. 1. Sea Trial Virtualization Schema

In the beginning, a simulation space is created, which takes into consideration all relevant virtual parameters for a vessel. Such information is available from blueprints of the prototype vessels and engineering information knowledge banks. From the simulations, simulated parameters of the vessel are obtainable like the trim (angle between the vessel and the engine), pitch, and drag. The next step was to understand whether these parameters are measurable directly or indirectly from the vessel. Many parameters (like vessel orientation and engine values) are directly obtainable via the NMEA2000 interface and were collected via the UMG. The drag of the vessel in the water is usually measured indirectly through accelerometers measuring acceleration values at specific points of interest within the vessel. By mapping these parameters to the CFD simulations, the gap between simulation space and actual sea trial conditions

¹ <https://hydrolift.com>

is narrowed. The data collected on the UMG via interfaces like the onboard systems (NMEA2000) and different sensor deployment via the UMG Nodes was logged at a fixed time interval. Fig. 2 shows a snapshot of parts of the sea trial live dashboard.

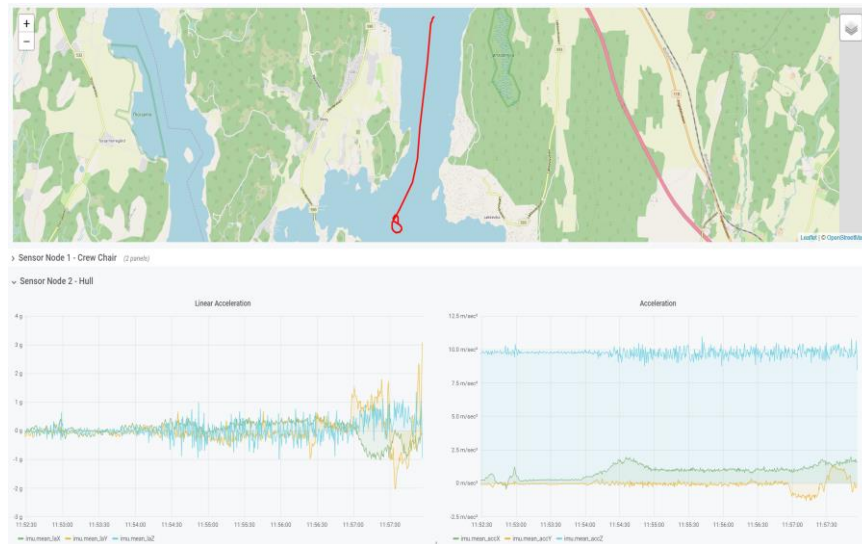


Fig. 2. Sea Trial Dashboard

Post sea trial, the data was curated and used in comparative analyses. Comparison between the measured parameters – namely, pitch angles of the vessel versus speed, engine/fuel consumption versus speed – were found to provide a more sensible representation than the interpretation of individual measurements. Finally, based on the analyses, an optimization of the vessel can be planned and validated through further simulations while at the same time, the initial simulation space can be refined.

5 Conclusion

This paper has presented an approach towards the virtualization of sea trials for the vessel prototype testing process. The proposed procedure relies on the capturing and integration of vessel-related sensor data into a knowledge-based engineering process. From the ideation and initial experimentation of the procedure first benefits for the vessel, developers have already been experienced in the form of increased understanding of the vessel's behavior under the test conditions. Also, the trust in the CFD simulation, which is being employed in the design process, has been increased.

To fully assess the viability and universal applicability in the vessel manufacturing domain, further experimentation is needed and foreseen. At the same time, the range of measurements will be expanded to allow to extend the scope from mechanical product development and validation, e.g., towards the assessment of the real lifecycle costs and emissions.

Acknowledgments. The research leading to these results has received funding from the Research Council of Norway within the project “Robust Industriell Transformasjon - RIT” as well as the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 727982. The contents of this paper reflect only the authors’ view, and the Commission is not responsible for any use that may be made of the information it contains.

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