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# Towards fault-tolerant decision support systems for ship operator guidance

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ABSTRACT

Fault detection and isolation are very important elements in the design of fault-tolerant decision support systems for ship operator guidance. This study outlines remedies that can be applied for fault diagnosis, when the ship responses are assumed to be linear in the wave excitation. A novel numerical procedure is described for the calculation of residuals using the ship's transfer functions which correlate the wave excitation and the ship responses. As tests, multiplicative faults have artificially been imposed to full-scale motion measurements and it is shown that the developed model is able to detect and isolate all faults.



## 1. Introduction

Today, onboard monitoring and decision support systems are installed on many commercial and navy vessels. In the present context, 'decision support' relates to operator guidance for the ship's master with respect to deciding on course and speed to keep wave-induced responses (motions, accelerations, etc.) below an acceptable limit. Typically, several responses are monitored by measurements from a system of sensors that could be as indicated in Fig. 1. The decision support system (DSS) is conceptually based on a principle which involves hydrodynamical and mathematical models in combination with information about the sea state (see Section 1.2). The overall idea is sketched in Fig. 2, where 'Output' is guidance in terms of predicted responses. The predicted responses apply to given operational conditions, including speed and course, and will facilitate an evaluation of risks associated to the considered conditions. In the end, this should lead to future response measurements below acceptable limits.

Decision support systems should be applied only when the quality of associated sensors and software is tested, securing the whole integrated system to be generally well-working, Nielsen et al. [23]. On the other hand, it can never be avoided that sensors, or their corresponding signals, at some stage, are likely to be corrupted by faults. It is therefore vital to be able to automatically detect any faults that may occur in a decision support system during operation, so that information/warnings can be issued about unreliable results. As a direct extension to 'fault detection' comes a wish to make a decision support system fault-tolerant. This means that the system has the ability to react on the existence of fault(s) by adjusting its activities to the faulty behaviour of the system. Fault-tolerant decision support systems for ship operator guidance are not standard, and little work has been done so far in the area. However, recent research has been initiated, e.g. Lajic [15], Lajic and Nielsen [17], Lajic et al. [16,18], and it is foreseen that many improvements in this area will be made in the future.

The present paper summarises important findings made in a recent Ph.D. work, Lajic [15], on fault-tolerant monitoring and decision support systems. Specifically, work was carried out to improve the reliability and dependability of decision support systems applied for matters of ship safety. This included the development of algorithms incorporating fault diagnosis techniques and improving the multi-sensor data fusion taking place in most monitoring and decision support systems.

### 1.1. Literature

Although the introduction of fault diagnosis techniques is new within the scope of decision support systems for ship safety, there is an existing literature on fault-tolerant approaches and algorithms for control of general ship components (engine, propulsion system, rudder, etc.) and particular responses. The present work has its foundation in some of this literature which includes: three papers by Blanke [3,4,6] in which fault diagnosis and fault-

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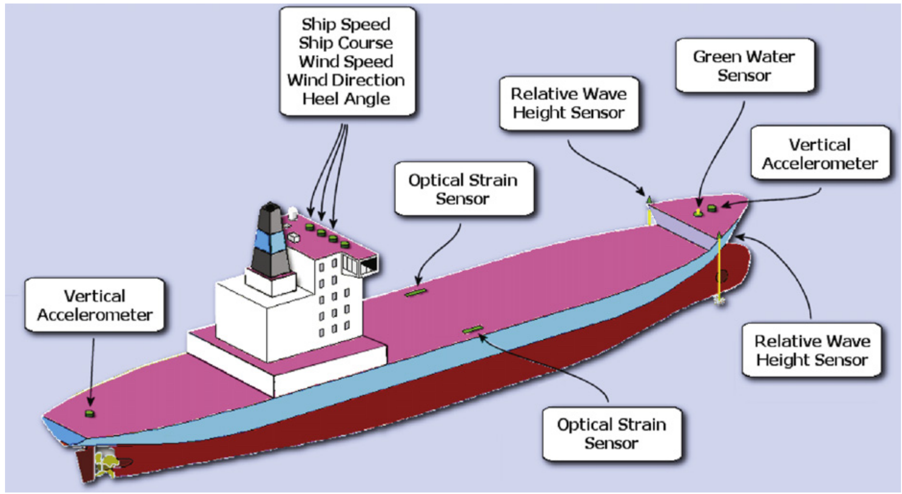


**Fig. 1.** Example of sensor arrangement on a ship.

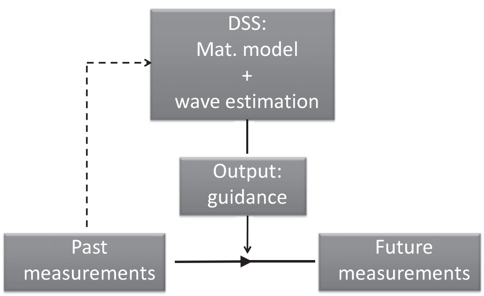


**Fig. 2.** Guidance is provided from a mathematical model and statistics of past measurements can be used to supplement shipboard wave estimations in the mathematical model [22].

tolerant control approaches are advocated for as means to enhance maritime and navigational safety. In Blanke et al. [7] the re-configuration possibilities for a ship propulsion system with a main engine and a controllable pitch propeller have been analysed and it has been demonstrated how fault tolerance could be achieved against a critical sensor failure. Similarly, sensor fault-tolerant control for a ship propulsion system is presented in Wu et al. [31], and implementation of the onboard control and monitoring system for unmanned underwater vehicles has been presented in Tiano et al. [30]. Furthermore, applications have been presented for early detection of parametric roll by Galeazzi et al. [10,11].

### *1.2. Sea state estimation*

A delicate and crucially fundamental part of decision support systems is the part which concerns the onboard estimation of the sea state at the advancing ship's exact position in the ocean. Thus, the combined use of the estimated sea state and mathematical/hydrodynamical models of the ship's behaviour to waves makes it possible to (statistically) predict about the future responses of the ship expected in, say, a 30 min horizon. Basically, two approaches exist for onboard sea state estimation: (1) the wave buoy analogy, which processes measured ship responses to give an estimate of the wave environment and (2) wave radar systems. The use of satellite data is not yet a feasible approach for onboard wave measurements, although in the future this could change. The present work relies on the wave buoy analogy [12,20,21,24,27,26,29] where the fundamental input is a set of response measurements (motions, accelerations, strains, etc.). In

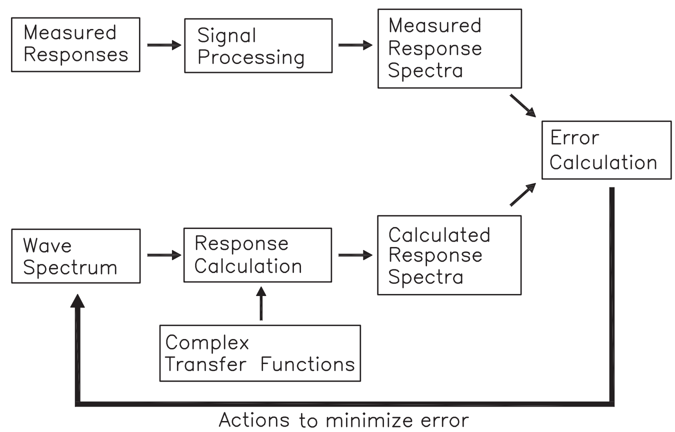


**Fig. 3.** The fundamental idea in the estimation of wave spectra based on measured ship responses.

this way, the way buoy analogy utilises onboard response measurements that are often carried out irrespectively on many of today's naval and commercial vessels. Consequently, the wave buoy analogy is a relatively inexpensive estimation concept, since the system development is associated with software only [24]. The wave buoy analogy as such will not be considered herein but a graphical illustration of the procedure is given in Fig. 3 [1] and detailed information can be found in the given references.

### *1.3. Objectives*

The overall objective of this work is to improve the reliability and dependability of decision support systems for ship operator guidance with respect to wave-induced responses. In general, the following techniques are suggested to improve the overall reliability and dependability of onboard systems:

- *Fault diagnosis* means to detect the presence of faults in the system. Faulty signal(s) should be discarded from the procedure for sea state estimation if it is possible, if not the fault should be estimated. When the sea state estimation is conducted by the wave buoy analogy, e.g. [20,21], it is sufficient to use three different ship responses and usually the responses of more sensors are available.
- *Sensor fusion quality test* means to decide which three ship responses would be the most suitable combination for wave