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Performance analyses of naval ships based on engineering level of simulation at the initial design stage

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Abstract

Naval ships are assigned many and varied missions. Their performance is critical for mission success, and depends on the specifications of the components. This is why performance analyses of naval ships are required at the initial design stage. Since the design and construction of naval ships take a very long time and incurs a huge cost, Modeling and Simulation (M & S) is an effective method for performance analyses. Thus in this study, a simulation core is proposed to analyze the performance of naval ships considering their specifications. This simulation core can perform the engineering level of simulations, considering the mathematical models for naval ships, such as maneuvering equations and passive sonar equations. Also, the simulation models of the simulation core follow Discrete EVent system Specification (DEVS) and Discrete Time System Specification (DTSS) formalisms, so that simulations can progress over discrete events and discrete times. In addition, applying DEVS and DTSS formalisms makes the structure of simulation models flexible and reusable. To verify the applicability of this simulation core, such a simulation core was applied to simulations for the performance analyses of a submarine in an Anti-SUrface Warfare (ASUW) mission. These simulations were composed of two scenarios. The first scenario of submarine diving carried out maneuvering performance analysis by analyzing the pitch angle variation and depth variation of the submarine over time. The second scenario of submarine detection carried out detection performance analysis by analyzing how well the sonar of the submarine resolves adjacent targets. The results of these simulations ensure that the simulation core of this study could be applied to the performance analyses of naval ships considering their specifications.

Keywords: Performance analysis; Simulation-based design; Modeling and simulation; DEVS; Naval ships

1. Introduction

Naval ships include various surface ships and submarines. They are assigned different missions, such as search and rescue, maritime patrol, anti-surface warfare, and anti-submarine warfare. These missions require different degrees of effectiveness, and naval ships must achieve these standards. The performance of naval ships is important for their effectiveness, and this performance depends on the specifications of their components. These components include hulls, propellers, rudders, fins, and sonars. For example, the rudders and fins of naval ships affect their maneuvering performance, while their sonars affect their detection performance. Such performance should satisfy their expected effectiveness in various missions. This requires performance analyses at the initial design stage. In other words, the specifications for the components should be determined with performance analyses.

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Modeling and Simulation (M & S) is an effective method for performance analyses from the aspects of cost and time. Broadly defined, modeling is a method for organizing knowledge accumulated through observation or deduced from underlying principles, while simulation refers to a method for implementing a model over time (Etter, 2013). Such M & S has also been used a lot in the case of naval applications. Vrijdag et al. (2007) discussed an efficient type of differential sensitivity uncertainty analysis method which is applied to the ship mobility model. Michetti et al. (2010) introduced a Ship Management System (SMS) which is able to integrate different systems onboard in order to monitor, control and manage whole systems or part of systems, single machineries and equipment. This SMS was optimized by using the ship simulation model. And, Martelli et al. (2014a) developed a simulation model suitable for Controllable Pitch Propeller (CPP) control system design and testing. Also, Martelli (2015) presented a propulsion control design approach where consolidated methodologies and newly developed procedures are linked together into the same simulation environment.

In the case of naval applications, there are four principal levels of simulation: theater, mission, engagement, and engineering. The theater level of simulation is generally applied to evaluate force structures or strategies. Next, the mission level of simulation is normally applied to evaluate force employment concepts. The engagement level of simulation is mostly applied to evaluate system alternatives or tactics. Lastly, the engineering level of simulation is mainly applied to design and evaluate systems or support system testing. For performance analyses to determine the specifications for the components of naval ships, the engineering level of simulation is required. This engineering level of simulation assists naval ship designers in decision-making. A simulation core is proposed in this study for such simulations. There exist mathematical models that represent naval ships for the engineering level with high fidelity. Also, these simulation models follow Discrete EVent system Specification (DEVS) and Discrete Time System Specification (DTSS) formalisms, so that simulations can progress over discrete events and discrete times. This paper introduces the details about this simulation core and its applications.

The remainder of this paper is structured as follows. Section 2 describes the related works on simulations for performance analyses in naval applications. Section 3 explains the theoretical background for the simulation core, including maneuvering equations, rudder and fin control, passive sonar equations, signal propagation, and DEVS and DTSS formalisms. The study used this simulation core to carry out the performance analyses of a submarine. Section 4 proposes a simulation core and Graphic User Interface (GUI) for the performance analyses of naval ships. Section 5 presents the applications of the proposed simulation core to the performance analyses of a submarine in an Anti-SUrface Warfare (ASUW) mission. Section 6 concludes this paper, and describes future works.

2. Related works

Li et al. (2012) analyzed the detection performance of active and passive sonar on naval ships, considering sonar equations and signal propagation. These considerations refer to mathematical models for the detection performance of sonars. Through various scenarios, the detection performance of sonars was analyzed according to different target types, sonar parameters, and sea conditions. However, these simulations did not consider the maneuvering performance of the naval ships. Son (2012) focused on the maneuvering performance of submarines. Mathematical models for their maneuvering performance were considered, applying maneuvering equations. Also, DEVS and DTSS formalisms were applied for the flexibility and reusability of simulation models. However, the sonars of the submarines were not considered. Kaymal (2013) analyzed which ship design factors were key drivers in the performance of surface ships in ASUW, based on realistic ASUW scenarios. In analyzing their performance, the key factors were compared for various ASUW scenarios. Although the ship design factors that were the key drivers in their performance were obtained, mathematical models were not considered. Lind (2014) focused on the maneuvering performance of submarines. The mathematical models for their maneuvering performance were considered, applying maneuvering equations and rudder and fin control. However, sonars of the submarines were not considered; nor were mission scenarios, such as maritime patrol or anti-submarine warfare. Khaledi et al. (2014) analyzed the detection performance of UUVs in mine detection missions. The detection performance was analyzed through the possibilities of mine detection, and the time and energy they took. Although mathematical models for the detection performance applied sonar equations to determine the possibilities of mine detection, the mathematical models for maneuvering performance of the UUVs were not considered in determining the time and energy. Martelli et al. (2014b) focused on the maneuvering performance of naval ships. The maneuvering performance was analyzed through mathematical models considering maneuvering equations, propulsion plant dynamics, propeller pitch change mechanism, and propeller propulsion control. In the aspect of maneuvering performance, it is inspiring to consider naval ship simulation including propulsion, maneuvering and control system. However, there was no considerations of detection performance and mission scenarios. In this study, a simulation core is proposed for both the maneuvering and detection performance analyses of naval ships. This simulation core can perform the engineering level of simulations for both performance analyses with high fidelity, applying mathematical models such as maneuvering equations, rudder and fin control, passive sonar equations, and signal propagation. Also, DEVS and DTSS formalisms are applied, making the structure of simulation models flexible and reusable. In addition, these specifications enable simulations to progress over discrete events and discrete times following mission scenarios. This study carried out the maneuvering and detection performance analyses of submarines using such a simulation core. Table 1 shows a summary of related works on simulations for performance analysis in naval applications.

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