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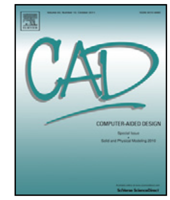

Learning-based ship design optimization approach

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ABSTRACT

With the development of computer applications in ship design, optimization, as a powerful approach, has been widely used in the design and analysis process. However, the running time, which often varies from several weeks to months in the current computing environment, has been a bottleneck problem for optimization applications, particularly in the structural design of ships. To speed up the optimization process and adjust the complex design environment, ship designers usually rely on their personal experience to assist the design work. However, traditional experience, which largely depends on the designer's personal skills, often makes the design quality very sensitive to the experience and decreases the robustness of the final design. This paper proposes a new machine-learning-based ship design optimization approach, which uses machine learning as an effective tool to give direction to optimization and improves the adaptability of optimization to the dynamic design environment. The natural human learning process is introduced into the optimization procedure to improve the efficiency of the algorithm. Q-learning, as an approach of reinforcement learning, is utilized to realize the learning function in the optimization process. The multi-objective particle swarm optimization method, multi-agent system, and CAE software are used to build an integrated optimization system. A bulk carrier structural design optimization was performed as a case study to evaluate the suitability of this method for real-world application.

1. Introduction

Ship design is a complex and distributed process, and with the development of computer applications in ship design, optimization plays an important role in this process. Optimization has been a particularly effective tool in ship structural design and analysis; however, the length of time required for optimization, which often lasts from weeks to months, has been a bottleneck problem for practical applications. Designers always try to reduce the runtime and speed up the convergence of optimization as much as possible. One of the most common methods is to use the designer's experience to assist the optimization. However, the specialist's experience and skills depend too much on personal ability, which means that the design process will become very sensitive and the design quality cannot be guaranteed. At the same time, the design conditions and variables often change dynamically during the whole design process, thus making the design very unstable.

This paper presents a new machine-learning-based optimal ship design approach, which introduces the human learning process into the practical ship design and analysis to improve the efficiency of optimization. Reinforcement learning as an important machine learning method is employed here to solve the sensory memory and partial short time memory problem due to its satisfactory real-time learning performance. *Q*-learning, as an idiographic approach of reinforcement learning, is selected and realized via a multi-agent system in this study. This method can guide the direction of optimization via experience learning and can assist the system to further adjust the ship design environment. The proposed method is tested on a real bulk carrier structural design case. The paper begins with an introduction of the work, followed by the background of optimization applications in ship design and structural analysis. Section 3 presents the new learning-based ship optimization method together with a brief introduction of human learning theory. Section 4 focuses on the application of the proposed approach on ship structural design, while the advantages and disadvantages of the application of this method are discussed in Section 5.

2. Background

Due to the complexity and dynamics of ship design, naval architects try to use many types of reliable and adaptive approaches to assist in the design work geared at improving the design quality. With the development of CAD and CAE technology in computer science, optimization has become more and more important, both in improving the performance of vessels and in obtaining better economic benefits while satisfying the requirements of rules and regulations. During the 1960s, the

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concept of computer-aided ship design began to appear, enabling the computer to play a more important role in ship design [1]. With the rapid popularization and development of computer-aided ship design, this has become an important research direction of ship design. These optimization methods are powerful tools that greatly reduce the complexity of design work and improve the quality of the final solution. As per the available research results, the MOGA (multi-objective genetic algorithm) – one type of heuristics method – appears to be a promising solution to complex ship design optimization problems.

Ray and Sha [2] incorporated accepted naval architectural estimation methods, a decision system handler, a nonlinear optimization tool and a containership model for the application. Ray et al., in [3–5], also provided a partial discrete optimization model, a global optimization model and an artificial neural network (ANN) application for ship design, respectively. A back propagation network model that undergoes supervised training was accepted, and the structure of the neural nets with the method of implementation was given. Thomas [6,7] used Pareto ranking, MOGA and NPGA to investigate the feasibility of full-stern submarines. Three objectives were considered: maximization of the internal volume, minimization of the power coefficient for ducted propulsor submarines, and minimization of the cavitation index. Binary representation and different selection techniques were used. Thomas also compared several different algorithms and reached the conclusion that MOGA outperforms the other methods in all of the aspects considered. Brown and Thomas [8] used a GA with Pareto ranking for naval ship concept design. Two objectives were considered: maximization of the overall measure of effectiveness (this factor represents customer requirements and relates ship measures of performance to mission effectiveness) and minimization of life-cycle cost. A binary representation and roulette wheel selection with stochastic universal sampling were used. Brown and Salcedo [9] and Brown and Mierzwicki [10]introduced a multi-objective genetic algorithm in naval ship design. Todd and Sen [11] used a variant of MOGA for the pre-planning of containership layouts (a large-scale combinatorial problem). Four objectives were considered: maximization of the proximity of containers, minimization of the transverse center of gravity, minimization of the vertical center of gravity, and minimization of unloading. A binary representation and roulette wheel selection with elitism based on non-dominance were used. They used the same algorithm for the cutting shop problem in the shipyard [12,13]. Two objectives were considered: minimization of the makespan and minimization of total penalty costs. Ray et al. [14] presented an evolutionary algorithm for generic multi-objective design optimization problems. This algorithm was based on nondominance of solutions in the objective space and constraint space and used effective mating strategies to improve solutions that were weak in either spaces. Ray and Tsai [15] applied a swarm algorithm for the shape optimization of airfoils on single- and multi-objective optimization. The proposed swarm algorithm was based on a socio-behavioral model, and three different airfoil designs were used as case studies. Peri and Campana [16] proposed a multidisciplinary design optimization of a naval surface combatant and developed high-fidelity models and multi-objective global optimization algorithms in simulation-based design [17]. Ölçer [18] proposed a hybrid approach for multi-objective optimization problems in ship design and shipping. In his study, the software 'modeFRONTIER' was used to perform the optimization via MOGA. Boulougouris and Papanikolaou [19] introduced a multi-objective optimization of a floating LNG terminal and utilized the software 'modeFRONTIER' with MOGA. Pinto et al. [20] presented a deterministic method for multi-PSO and applied the method to the multi-objective (two objectives) seakeeping of the containership problem. Cui and Turan [21] proposed a new multi-PSO method, HCPSO, and applied it to three objective optimization of ship stability design.

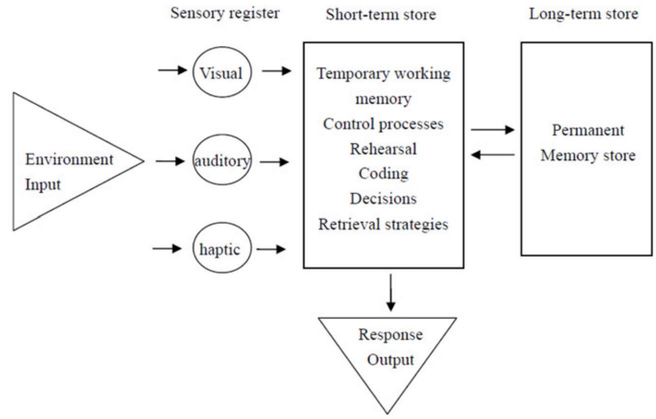

Fig. 1. The model of Atkinson and Shiffrin summarized by Baddeley.

Rigo [22] published a detailed, state-of-the-art paper in 2003 on a structural optimization research field. He introduced the concept and development of ship structure optimization from the 1960s to 2003. In the same paper, Rigo introduced the optimization software LBR-5, while Richir et al. [23] used this software [22] to solve a three-objective optimization problem. The production cost, weight and moment of inertia were selected as objectives, and a two-stage local search heuristic approach (CONLIN) was accepted as the optimization algorithm. Zanic et al. [24] introduced a decision support methodology including optimization for a multi-deck ship structure. Klanac [25] proposed vectorization and constraint-grouping approaches to enhance the optimization of a fast ferry structure. Klanac [26] introduced a two-stage optimization approach for collision simulation. Eamon and Rais-Rohani [27] presented a reliability-based optimization method for a composite advanced submarine sail structure. Jang [28] employed a multi-objective genetic algorithm to solve a two-objective optimization problem. Sekulski [29] used a genetic algorithm to solve the problem of weight minimization of a high-speed vehicle–passenger catamaran structure.

3. Learning-based ship optimal design method

The learning-based ship optimal design method aims to simulate natural human learning to assist ship optimization design. Therefore, the design system can draw experience from design actions automatically to assist the ongoing work. In this method, the ship design process can be analogized to the life of a human. During every single design process, the method will learn the instantaneous experience, and following a particular design exercise, this experience may be valued as very useful knowledge to store in the system. With the increasing number of the design cases, the system will improve its ability step by step via learning.

3.1. *Brief introduction of learning theory*

Although learning science has been developed since the 1990s [30], the mechanism of human memory storage is very complex, and the detailed process of memory storage has been a vexing subject of research for a long time. In this study, the popular learning model of Atkinson and Shiffrin was accepted along with the improved working memory concept developed by Baddeley [31].

In the memory model of Atkinson and Shiffrin (as shown in Fig. 1), the memory process is divided into three parts: sensory memory, short-term memory and long-term memory. Sensory memory is immediate memory, which normally persists for only several seconds. Long-term memory is that which enables people