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Expert system based on the arrangement evaluation model for the arrangement design of a submarine

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ABSTRACT

The arrangement design of a submarine depends on the past design data and experts' experiences. Delay in design can occur due to data missing or the absence of experts. In addition, various compartments and equipment are placed on the limited space called *pressure hull* in the submarine, so that the relation between the compartments and equipment should be considered carefully when designing the arrangement of the submarine. In this sense, there is a need to accumulate data regarding the past design data, experts' experiences, and design rules as a systematic structure. To meet such a demand, an expert system for the arrangement design of a submarine was proposed based on an arrangement evaluation model (AEM) in this study. The expert system can systematically computerize experts' experiences and knowledge, and can evaluate the feasibility of design alternatives for the arrangement design of the submarine. In addition, an arrangement template model (ATM) was proposed to store various information on the arrangement design of the submarine. To evaluate the applicability of the proposed expert system, a prototype program consisting of an arrangement evaluation module and the arrangement template model was developed. Finally, this program was applied to a problem of a small submarine. The results showed that the proposed expert system can be used to evaluate the given design alternatives for the arrangement design of the submarine.

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1. Introduction

1.1. An arrangement design of a submarine

The arrangement design of a submarine is similar to layout design of a building. However, in the case of the submarine, restrictions on the weight and the center of gravity (COG) of the submarine should be considered (Burcher & Rydill, 1994). In addition, the crew only can operate inside of the submarine called *pressure hull*, so the arrangement design of compartments and equipment inside of the pressure hull should be rigorously considered with more caution. Before the arrangement design stage, principal dimensions of the submarine are determined first. Then, a rough arrangement of the submarine is drawn up. After the rough arrangement is made, a detail arrangement of the submarine is determined including equipment and outfit. At this time, a 3D CAD model (digital mock-up) can be used for checking and modifying the arrangement as occasion demands. Sometimes, a scaled or real scale model can be used for the validation or improvement of the arrangement considering the operability of the equipment, the accessibility of passage, and so on (Son & Park, 2001). Thus, the efficiency of the space inside the pressure hull is very important, so that efforts of design experts should be reflected in the arrangement design of the submarine.

As a hull form of a submarine, a teardrop form is ideal because it is advantageous in underwater voyage. However commonly, a hull form of many submarines is longer and thinner than the teardrop form because of the convenience of the arrangement. As considering this, inside of the pressure hull should be tight in the space usage. Dominant components of the length of the pressure hull are a torpedo room, a propulsion system, a battery, and so on. The torpedo room and the propulsion system are very hard to shorten because of the characteristics of the equipment included in the systems. Thus, experts always consider to pile up the dominant components of the length. For example, they allocate the space for the battery room under the torpedo room. There are also restrictions on the depth and the breadth considering the size of the hull form, so that the arrangement design of the submarine should be performed to take account of the arrangement components synthetically (Zimmerman, 2000).

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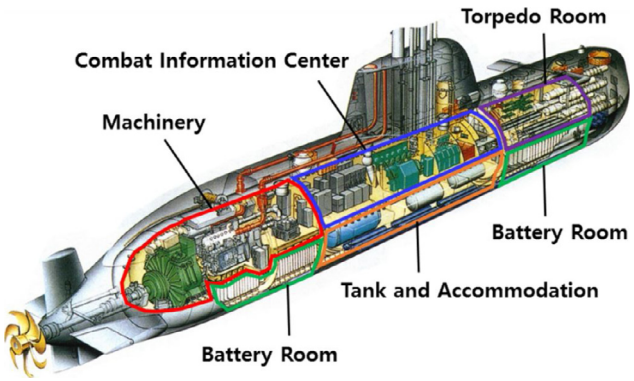

Fig. 1. Example of the arrangement of a 212 class submarine of Germany.

For some functions of the submarine, various tanks having liquids should be placed in the pressure hull. A compensation tank placed in the middle part of the pressure hull and trim tanks placed in the front and the rear part of the pressure hull are used to compensate the weight variation of the submarine while operating. For example, the weight of the fuel oil and the auxiliary oil is changed during an operation, and its COG is also changed. Thus the compensation tank and the trim tanks should be properly arranged. Furthermore, the fresh water tank and the sanitary tank are installed for the crew. In various cases of the arrangement of the submarine, efforts to lower the COG is necessary because of the stability of the submarine. Fig. 1 shows an arrangement of a 212 class submarine of Germany equipped with a diesel propulsion system.

1.2. Research background

The arrangement design of a ship has been performed referring to the previous ships and by modifying some parts of these when needed. In the case of the arrangement design of a submarine, however, there are few data available about the previous submarines. Thus, the role of experts is extremely important in the stage of the arrangement design. Also, the arrangement design of the submarine is dependent on the limited data regarding the previous submarines and experts' experiences. Delay in design can occur when there are missing data or when experts are absent. At this time, there are many design methods and tools available to support a designer. Some of them are now available as commercial computer programs (Edwards, 2003). However, design of a product is no longer considered as a problem solving procedure. With the initiation of technology and competent programs for computation, it has become more of a decision making process that involves precise assessment of design alternatives (Ipek, Selvi, Findik, Torkul, & Cedimoglu, 2012). Thus, an expert system can be one of the alternative solutions to such problem or process.

The expert system involves systematically computerizing experts' experiences and knowledge. The arrangement design experts have difficulty calculating complicated, quantitative values such as material flows and space efficiency, but they can take account of many things, such as the efficiency, manufacturability, and maintenance aspects of the submarine, relying on their experiences and knowledge. If the expert system is well developed and is applied in the stage of arrangement design, it can be used to evaluate the feasibility of an arrangement design alternative instead of relying on experts for each design instance. Thus, an expert system that can systematically computerize experts' experiences and knowledge, and can evaluate the feasibility of design alternatives for the arrangement design of the submarine was developed in this study.

1.3. Related works

As mentioned earlier, most of the equipment in a submarine, which is a special kind of ship, are placed in a limited space called *pressure hull*. Thus, the arrangement design of a submarine requires greater efforts compared to the arrangement design of the conventional ship, due to the severe space limitations of the former. Many studies on arrangement design for ships have been conducted, but there have been a few studies on arrangement design for submarines because most submarines are made for military purposes and are kept secret from the public. Below is a summary of the past studies, related to arrangement design in the field of naval architecture and ocean engineering.

Byun (1998) proposed a rule-based expert system based on a knowledge base for supporting initial ship design such as compartment design at the initial design stage. He constructed the knowledge base for deciding the principal dimensions of a ship to obtain the maximum volume of cargo that can be carried by a ship as per the ship owner's requirement and the pertinent international regulations. In addition, he constructed a knowledge base for determining the arrangement of the compartments.

Shin, Kim, and Park (2002) proposed an expert system for the layout design of the machinery in a ship. They made rules for the layout design of machinery, from the relation between the equipment and the ship owner's requirement, the insights of the designer, etc. When evaluating the rules for coming up with design alternatives, they also considered fuzzy rules. Finally, they developed a new algorithm for the layout design of machinery using the expert system.

Helvacioglu and Insel (2005) proposed a multistage expert system for the arrangement design of a container ship (i.e., compartment arrangement). With the expert system, they divided a container ship into several large blocks called *function groups*, and initially arranged them to determine the compartment arrangement. By considering more detailed data, they derived the final arrangement of the ship's compartments. They used heuristic knowledge and rules for the container ship in the expert system.

Chung, Kim, Shin, Koo, and Kraus (2011) proposed a submarine arrangement design method based on an expert system and an optimization technique. In their method, a rule-based expert system, which is one of the expert systems, was used. The partitions dividing the pressure hull into compartments, and the sequence of the compartments, were selected as design variables for optimization. The evaluation values for the alternatives obtained from the expert system were used as an objective function for optimization. That is, if a certain alternative violates a rule, a penalty is added to the value of the objective function of the alternative. Their study, however, considered the two-dimensional arrangement, but the equipment of the submarine were not taken into account for the arrangement design.

Shin (2013) proposed a method for the arrangement design of a naval ship by considering its survivability at the initial design stage. The SLP (systematic layout planning) method was used for analyzing the relation between the equipment in the naval ship. Then an arrangement method for generating alternatives and evaluating them was proposed. The SLP method differs from the expert system in that the method decides the arrangement using the relation matrix between the equipment, but as such equipment is made by an expert, it is somewhat similar to the expert system.

There has been a research on the expert system in the field of architecture. Park (2009) proposed a framework for representing experts' knowledge called SLEM (spatial layout evaluation model) using the requirement of space (area, position, etc.) and the relation between the spaces (adjacency, level difference, etc.). Then he evaluated the given arrangement for a building using the proposed framework. Such method, however, could evaluate the building special section only. Thus, it has limitation to evaluate the arrangement of an interior or equipment in the building.

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