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Naval ship's susceptibility assessment by the probabilistic density function

Kwang Sik Kim, Se Yun Hwang and Jang Hyun Lee*

Department of Naval Architecture and Ocean Engineering, INHA University, 100 Inharo, Nam-gu, Incheon 402-751, Republic of Korea

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Abstract

The survivability of the naval ship is the capability of a warship to avoid or withstand a hostile environment. The survivability of the naval ship assessed by three categories (susceptibility, vulnerability and recoverability). The magnitude of susceptibility of a warship encountering with threat is dependent upon the attributes of detection equipment and weapon system. In this paper, as a part of a naval ship's survivability analysis, an assessment process model for the ship's susceptibility analysis technique is developed. Naval ship's survivability emphasizing the susceptibility is assessed by the probability of detection, and the probability of hit. Considering the radar cross section (RCS), the assessment procedure for the susceptibility is described. It's emphasizing the simplified calculation model based on the probability density function for probability of hit. Assuming the probability of hit given a both single-hit and multiple-hit, the susceptibility is accessed for a RCS and the hit probability for a rectangular target is applied for a given threat.

Keywords: Survivability; Vulnerability; RCS (Radar Cross Section); Probability of hit; Probability of detection

1. Introduction

When a naval ship in a modern combat environment is exposed to a threatening weapon and attacked, the combat system and hull structure suffer critical damage. The ability of a naval ship to withstand such threats encountered in a battle environment is defined as the survivability of the ship [1]. The survivability of the ship is evaluated by three types of stochastic indicators—susceptibility, vulnerability, and recoverability [1-3]. The most fundamental method for improving the survivability of the naval ship is to design the ship such that its susceptibility becomes close to zero. However, because it is difficult to attain zero susceptibility in reality, the realistic approach to improving the susceptibility involves considering various situations that may arise on being attacked [4]. The susceptibility of the naval ship refers to the probability of the ship being attacked by threatening weapons after being identified by an enemy's detection technology and equipment [4, 5]. Therefore, the signals generated by a naval ship, the devices for detecting and identifying these signals, and the defense and deception system employed against enemy's threatening weapons following detection need to be analyzed [6]. The susceptibility should be comprehensively evaluated by considering the shape of the naval ship's radar reflection area, infrared signal characteristics, electromagnetic equipment performance, and radiation noises [7]. Many studies have reported on the aforementioned evaluation factors indivi-dually [8], and the analysis field can be divided into Radar Cross Section (RCS), Infrared (IR), Underwater Radiated Noise (URN), and Electro Magnetic Interference (EMI) according to the respective detection characteristics and equipment [6]. In the present study, as a part of a naval ship's survivability analysis, a theoretical process model for the ship's susceptibility analysis technique was developed. The applicability of this model was demonstrated through an example model and arbitrary attack situations.

2. Susceptibility analysis of naval ships

2.1 Susceptibility analysis theory

To analyze the susceptibility of a naval ship, the characteristics and performance of the equipment used for detecting enemy naval ships, and the possibility of being hit by threatening weapons must be analyzed. In this study, the susceptibility analysis process model was constituted as shown in Figure 1 based on the stochastic theory. The attacking probability (P_H) is based on the detection probability (P_D), which is the probability of identifying the friendly naval ship by the enemy detection equipment, and on the hit probability (P_{hit}), which is the probability that the friendly naval ship could be hit by the threatening weapon after being detected. The at-

*Corresponding author. Tel. : +82-32-860-7345, Fax.: +82-32-864-5850
E-mail address: jh_lee@inha.ac.kr
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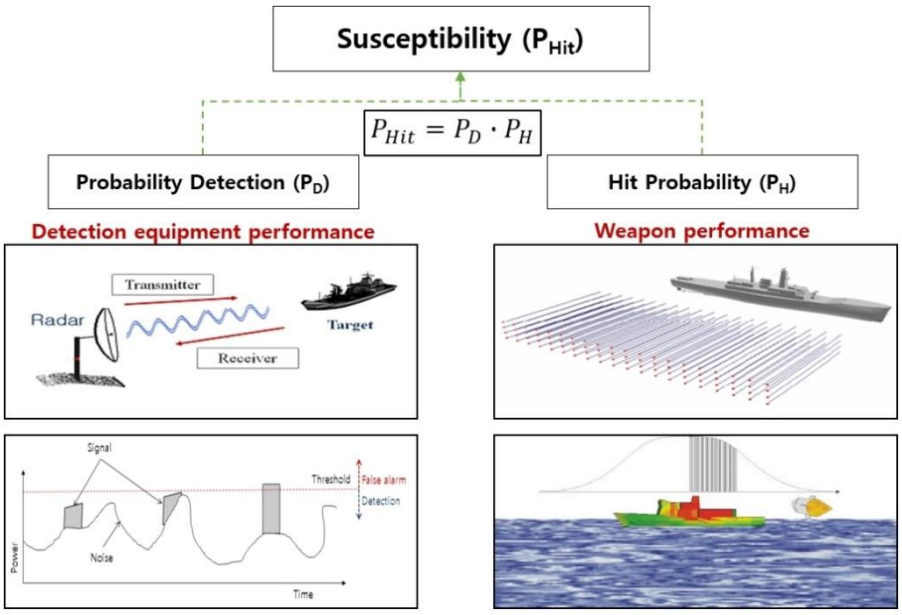

Figure 1. Mesh grid of topographic model.

tacking probability is expressed as shown in Eq. (1).

$$P_H = P_D \cdot P_{hit} \tag{1}$$

2.1.1 Detection probability

The detection probability is the probability that the naval ship (target) could be detected by the enemy detection equipment. The RCS detection characteristics and the threshold to noise (T/N) value, which is the minimum detection limit, are calculated on the basis of the signal to noise ratio (S/N) value. The S/N value is the degree of noise in RCS signal according to the cross sectional area (σ) of the radar [9] (Eq. (2)). RCS is the specified area to indicate the reflectivity of the radar's reflector when the electromagnetic waves emitted from the radar are reflected back by the target [7]. Therefore, the reflectivity value of the radar varies depending on the shape of the reflector [7]. Naval systems, including the naval ship's hull and fittings, have their own unique complex shapes, which have to be taken into account when calculating RCS; hence, each shape should be simplified as shown in Figure 2, and then, RCS should be calculated for each simplified shape [9].

$$P_D = \left[1 + \frac{2(T/N)(S/N)}{2 + (S/N)^2}\right] e^{-2(T/N)(2+S/N)} \tag{2}$$

S/N ratio value (dB) represents the extent of unnecessary noise in the signal [10, 12]. In other words, the S/N ratio represents radar signal-to-noise ratio (Figure 3), and it is proportional to the shape of RCS because it is calculated using the radar's cross-sectional area. The S/N value according to the RCS detection characteristics is defined as shown in Eq.

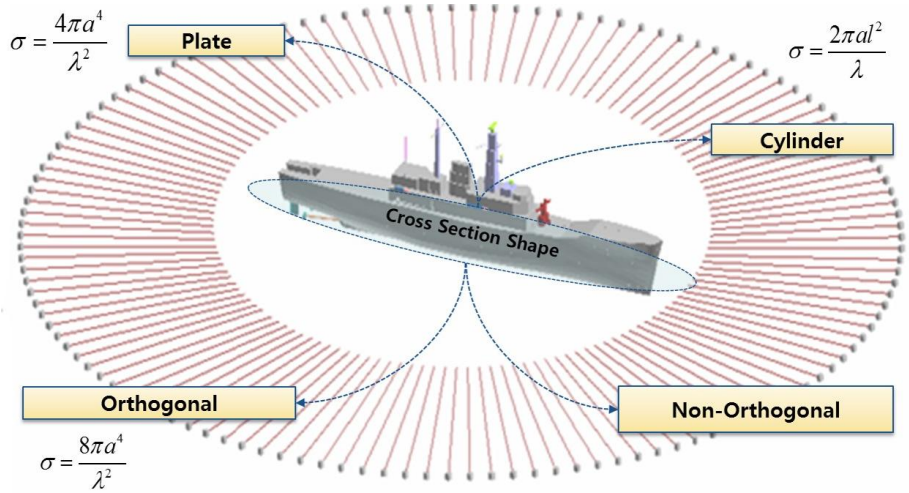

Figure 2. The simplified shape for hull and system.

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