

Impact Point Estimation of Radar-Homing Anti-Ship Missile based on Radar Cross-Section of Naval Ships

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This paper presents a novel method for estimating impact locations of radar-homing anti-ship missiles based on the radar cross-section characteristics of naval ships. The study employs two different approaches: one using multivariate distribution and the other data-driven machine learning techniques. The multivariate distribution method analyzes the correlation between variables, such as azimuth angle, elevation angle, and distance, enabling quick trend identification. In contrast, the machine learning approach provides more precise impact point predictions but requires significantly longer data analysis and model training time. Results demonstrate that the predicted impact locations using machine learning closely match the equivalent scattering center, whereas the multivariate distribution approach reveals a broader spread of impact points. Future work will include detailed mathematical formulations for multivariate distribution and covariance, as well as the complete machine learning algorithm.

Index Terms—Anti-ship missile, Electromagnetic wave, Equivalent scattering center, Radar, Survivability, Susceptibility.

I. INTRODUCTION

ONE of the key operational capabilities of naval ships is survivability, which is evaluated based on three aspects: susceptibility, vulnerability, and recoverability [1], [2]. Among these, susceptibility and vulnerability are closely related to stealth performance. Radar cross section (RCS) is a critical performance indicator directly linked to susceptibility, as it determines the detectability of a ship. To enhance the survivability of naval ships, it is essential to reduce susceptibility by minimizing RCS, estimate impact locations based on RCS signals, and conduct vulnerability analysis for various impact points. Therefore, this study proposes an estimating method of the impact locations by analyzing the characteristics of RCS signals based on the approach direction of radar-homing anti-ship missiles as they target naval ships. This paper introduces two estimation approaches: one based on multivariate distribution characteristics and the other utilizing data-driven machine learning techniques.

II. ANALYSIS MODEL

For the study of impact location estimation techniques, a 90-meter-class virtual ship was used as the analysis model for RCS evaluation. In RCS analysis, the more multiple reflection phenomena are considered, the longer the computation time required. Therefore, equipment installed on the ship, such as weapon and communication systems, was excluded from the analysis. As shown in Fig. 1, the numerical analysis model has dimensions of 90(m) in length, 13(m) in width, and 20(m) in height, and consists of 374 planar triangular elements. The ship's surface was assumed to be a perfect conductor, and multiple reflections were considered up to the third order.

III. RADAR CROSS SECTION ANALYSIS

Radar-homing anti-ship missiles detect and track naval ships by recognizing them as point scatterer. The RCS and location

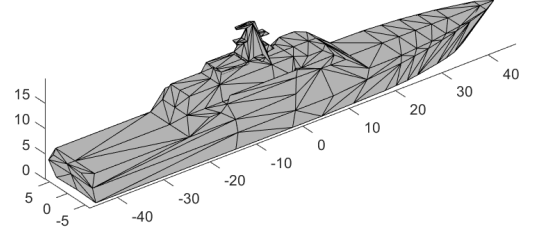


Fig. 1. Numerical analysis model of 90-meter-class virtual ship.

generated by the ship converge into a single equivalent scattering center, representing the distribution of scattering centers on the ship. In this study, the equivalent scattering center of RCS values for each scattering distribution are calculated as shown in (1) by distinguishing between single reflection and multiple reflection components based on the scattering characteristics of electromagnetic waves.

$$\sigma_{uv} = 4\pi \left| \sum_{i=1}^N S_{uw,i} \right|^2 = 4\pi \left| \sum_{i_1=1}^{N_s} S_{uw,i_1}^s + \sum_{i_2=1}^{N_m} S_{uw,i_2}^m \right|^2 \quad (1)$$

Here, σ_{uv} means the RCS value, N is the number of scatters combining the entire target, N_s is the number of single reflection scatters, N_m is the number of multiple reflection scatters, S_{uw}^s and S_{uw}^m are the scattering matrix elements for single reflection and multiple reflection, respectively.

The scattering center distribution of analysis model is analyzed by distance at intervals of 0.2 degrees for azimuth angles from 0 to 360 degrees and at intervals of 1 degree for elevation angles from 0 to 40 degrees, and the database of RCS values is created. Through the scattering center distribution, the equivalent scattering center can be calculated. Fig. 2 represents the equivalent scattering center when the distance is 2000 meters, the azimuth angle is 150 degrees, and altitude is 200 meters, marked with a large star. This equivalent scattering center of the RCS can be converted into coordinates and utilized as the impact point estimation.

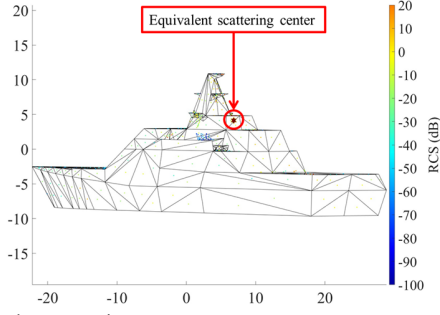


Fig. 2. Equivalent scattering center.

IV. IMPACT POINT ESTIMATION METHODS

A. Multivariate distribution characteristic

The RCS data of a naval ship varies in x, y, and z coordinates and RCS values depending on variables such as azimuth angle, elevation angle, and distance. By modeling this data using a multivariate distribution, the correlations between variables can be considered to predict the impact location. In particular, the covariance matrix enables the analysis of interactions between variables, which can be used to predict RCS values under new conditions.

Fig. 3 shows the multivariate distribution when the distance is 1000 meters. The result of the estimated impact location is shown in red in Fig. 4, assuming the missile is approaching from a distance of 10,000 meters, an altitude of 200 meters, and an azimuth angle of 150 degrees. In the case of the equivalent scattering center, the rear of the mast was identified as the impact location, whereas the impact points predicted using the multivariate distribution are spread across both the front and rear of the mast. Since the multivariate distribution is a probabilistic approach, it is important to carefully consider the missile's radar detection range to increase the probability of accurate prediction.

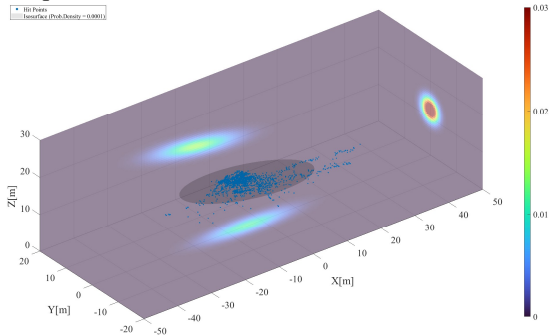


Fig. 3. The multivariate distribution.

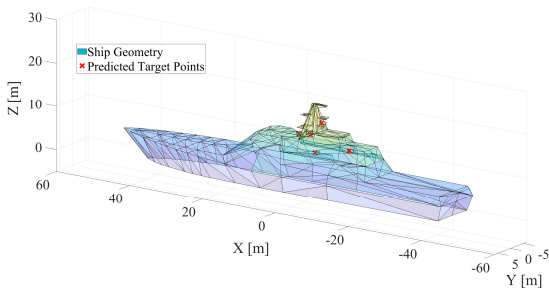


Fig. 4. Predicted impact points based on multivariate distribution.

B. Data-driven machine learning technique

As shown in Table 1, the training data was prepared, and an impact location estimation model was developed using artificial neural network-based machine learning. The result of the estimated impact location is shown in red in Fig. 5, assuming the missile is approaching from a distance of 10,000 meters, an altitude of 200 meters, and an azimuth angle of 150 degrees. Unlike the results of the multivariate distribution, the estimated impact locations from the machine learning model are concentrated at the rear of the mast. This result is also found to be very similar to the equivalent scattering center.

In the case of the machine learning method, the accuracy is much higher compared to the multivariate distribution method, but the time required for data analysis and model training is significantly longer than that of the multivariate distribution method.

TABLE I
TOTAL NUMBER OF ANALYSIS ELEMENTS

Item	Analysis condition	The number
Distance	10000m, 8500m, 7000m, 5000m, 2500m, 1500m, 1000m, 500m	8
Elevation angle	From 0° to 40° / 1° interval	41
Azimuth	From 0° to 359.8° / 0.2° interval	1800
Total number		590,400

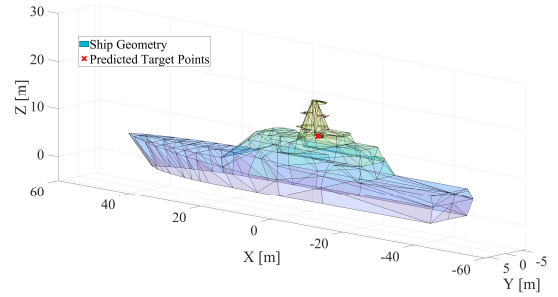


Fig. 5. Predicted impact points based on machine learning technique.

V. CONCLUSION

This paper presents a method for estimating the impact locations on a ship using two different approaches. The multivariate distribution method offers the advantage of quickly identifying trends, making it suitable for use in the preliminary design phase to assess vulnerability and susceptibility during ship design. On the other hand, the machine learning method can be utilized during the detailed design phase when precise analysis is required.

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