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Torpedo performance Markov model

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ABSTRACT

The improved evasive capability of the modern deiseal submarine can downgrade the performance of a torpedo seriously. However, a few studies have concerned the sophisticate diesel submarine as a main factor for the influence of a torpedo's attack. This paper presents a torpedo performance Markov model for making quick analyses on a torpedo performance in pursuit of a diesel submarine under various conditions. This model takes into account the effectiveness of submarine's counter measures and maneuvering behaviors of both sides. The Markov process is used and six states are sorted out for representing the dynamic behaviors for both of submarine and torpedo systematically. Through cases analyses, we prove that the torpedo performance is deteriorating exponentially as the number of counter measure is increasing. This analytical result may refine the anti-submarine warfare decision to avoid the possible misleading by solely relying on the deterministic torpedo probability of kill in the engagement. It also identifies that two pairs of jammer coupling with two decoys can be the best combination to saturate torpedo attack that can direct provide the decision makers a basic doctrine for controlling their engagement behaviors.

1. Introduction

Anti-Submarine Warfare (ASW) is a complicated warfare as the nickname "Awfully Slow Warfare" refers, because it is time-consuming to search for a submarine, which is quiet and deadly (Ketter, 2004; Stavridis, 2014). In fact, searching for a submarine is not only time-consuming but costly because it requires the coordinate operations supported by the ASW assets from air, surface and subsurface. For this reason, the ASW decision making process is used to focus on the search phase instead of attacking phase. Thus, most of current ASW models or simulation systems, such as such as the underwater warfare software simulation toolset (named ODIN), object-oriented rule-based interactive system (ORBIS), joint theater level simulation (JTLS), and integrated theater engagement model (ITEM) etc., ranging from the level of campaign to engagement, incline to just simplify the submarine engagement or to the area of submarine detection in terms of training, exercise, as well as the analyses (Higgins, Turriff, & Patrone, 2002; Leader, 2010; Nunn & Heimerman, 1994; Robinson, 2001). To compare the phase of attack to search in ASW, the importance of torpedo attack is nearly ignored because the result of it is very easy to be substitutes by a constant value. However, owing to the advanced technology, submarine has become one of the most versatile platforms with the characteristics of less noise, stealthy and powerful weapon which can make a formidable threat to surface ships. Tiny lapse can lead to a huge mistake. It will be a devastated situation if the survived submarine has second chance to make attack to the ASW forces. For this reason, it is significant to understand how much difference the submarine can make to torpedo performance, and then it is possible to avoid the potential miscalculation in ASW.

We strongly believe that any difference of torpedo performance can affect the battle significantly. But how much torpedo performance can be affected by the submarine's countermeasure (CM) and its maneuverability is the area of interest in this research. The objective of this paper is to study the dynamic behavior of lightweight torpedo in pursuing a diesel submarine and to model their pursuer-evader behaviors by Markov process and to develop torpedo performance Markov model (TPMM) to evaluate the performance of torpedo in against submarine under uncertain situations. Taking advantage of Markov process, we may draw the tactical dynamic behavior of torpedo and submarine in and transform the behavior into Markov state.

This paper is organized as the follows. The related works will be reviewed in section two. The modeling process is in section three. Cases study and analyses are in section five. Section six concludes the paper and provides the findings.

2. Literature review and related work

2.1. Literature review

ASW issue has been discussed across a broad level of the war at sea including strategy, campaign, tactics, technology, research and

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development since submarine emerged as a threat. ASW tactics has been improving with the pace of advancement of technology including platform's speed, depth, noise reduction, detection, tracking and weapon performance. The analytical oriented research literatures of ASW are relatively sparse and the specific issue about torpedo performance is even rare.

Owing to the complex feature of ASW, Monte Carlo simulation has been widely used to support ASW applications. There are some studies provide a valuable references for the better understanding of ASW modeling process. Lautour and Trevorrow (Lautour & Trevorrow, 2012) indicated the ODIN is a general ASW model with multi-levels fidelity used to have insight of ASW for an advanced concepts and system design of future systems. In Knippenberg (2014), MANA is introduced to replace Underwater Warfare Testbed (UWT), which is too complex to be capable of quick analyses, for testing warship concepts in an early phase of ship design. In fact we are more concerned a torpedo effectiveness in its pursuit to a target. In Seo, Choi, Kim, & Kim (2014), discrete event system specification (DEVS) is used to develop engagement-level simulation for analyzing the surface ship survival rate when a surface warship found it is pursued by a submarine torpedo attack. In Harivamsi, Sashidhar, Gautam, & Rao (2011) have proposed a simple but concept essential method, which is relative bearing measurement only simulation, that can evaluate the effectiveness of the employed soft kill counter measures ship to survive an attack from torpedo.

2.2. System behavior and modeling techniques

A distinctive feature of torpedo-submarine interactive behaviors modeling which can be regarded as one of the pursuit-evasion scenes, when compared to other modeling techniques mentioned above like simulation, is the preservation of the interaction with engagement logic. Having the complex pursuit-evasion scene between a torpedo and a submarine been simplified, the modeling concept has to consider the pattern of interactive behaviors and the method of modeling.

The pursuit-evasion problem, such as cops-robbers or predator-prey, used to be treated as game called pursuit-evasion game, has been extensively studied. In Isaacs (1999), Homicide Chauffeur game has been introduced to guarantee capturing the evader. In Walker (2005), a school of herring's behavior has been analyzed for the tactics of minimizing encounters or attacks from predators. Khan (2007) has engaged pursuer-evader game (PEG) by using simple game theory models. In Isler & Karnad (2008), graph algorithm has presented for solving cops and robbers game with result showing that that the reduction in cop's visibility can result in an exponential increase in the capture time.

In previous work, we have explored the behavior of pursuer and evader, finding the fundamental behavior of torpedo in pursuit of submarine is resembled but with more complicated dynamic interaction. For this reason, some studies have made a great contribution on the more complex interactive behavior in PEG with Markov process. In Givigi & Schwartz (2014), a pursuit-evasion game is modeled with Markov chains for being able to interpret each player in the multiple pursuers and evaders game can be as a decentralized unit that has to work independently in order to complete a task. In Coffman, Margolies, Winkler, & Zussman (2014), the fragmentation process, which was modeled by Markov process, has been used to analyze file allocation in disk-based storage and dynamic spectrum access in terms of the interest of more efficient utilization. In the specific ASW area, few studies have presented using Markov chain to interpret the warfare PEG. In Marsh & Piacesi (1988), a steady state Markov process has been used to quantify strategic missile submarine force survivability in an ASW surveillance-surge attack scenario. In Frye & Korsak, (1973), they made success and fail of the warfare engagement as absorbing (trapping) states, which are

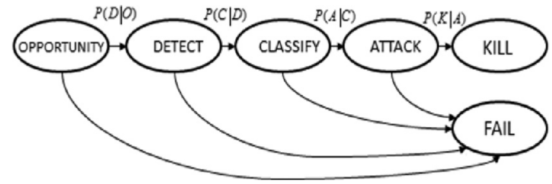

Fig. 1. A Markov process with six states.

defined as the end of analysis. The sequence of submarine detected, classified, attacked, and killed has been transformed into the opportunity-detect-classify-attack-kill chain states, such as Fig 1. This chain has been renovated as kill-chain and is employed by US Air Force (Lo & Au, 2010; Marzolf, 2004). In Rice (2007), a kill-chain has been simplified as "Find-Fix-Finish" (FFF).

The transition diagram for the effectiveness of the weapon system can be derived as Fig. 1.

In the domain of ASW system performance, some studies have provided the remarkable modeling techniques and the analytical results. In Gao, Yang, & Zhang (2010), a Monte Carlo simulation model for analyzing the effectiveness of submarine in against torpedo has been proposed. A combination of speed of submarine and the exact time of releasing countermeasure has been simulated. Under the 18 knots speed of submarine scenario, using decoy and jammer can have a different survivability, i.e., 0.27 and 0.24 respectively. In Liang & Wang (2006), a hybrid model which the evolutionary algorithm and simulation were blended, for finding the optimal submarine evasion tactics. In Armo (2000) and Akbori (2004), the expected survivability model of submarine attacked by torpedo has been presented.

3. Model

3.1. The concept of the operation and engagement processes of a torpedo

In concept, the operation of a torpedo can be divided into two major modes in terms of interactions, search and attack. The interactions begin with the torpedo being launched from the ASW platform. Once in the water, the torpedo swims away from the launch point and commences its search mode; initially, the torpedo performs a snake-like search and then shifts to a helical search trajectory using a conical acoustic window to acquire its target. When the signal of submarine has been identified, the torpedo transitions into attack mode for homing of the target. This is a very basic torpedo operation that is carried out against a submarine when no counteractions are encountered.

Most modern submarines are equipped with CMs to counter torpedo attacks, where devices include jammers and decoys that generate a jamming and deceiving environment for the torpedo, respectively. Additionally, the maneuverability in terms of speed and depth also is considered an important part of the submarine's evasive tactics. To orchestrate these variables in countering a torpedo attack, from a high survivability perspective, the submarine should take the correct tactical actions by calculating the appropriate timing when changing its speed or depth and when releasing its jammers and decoys. Hence, the concept of torpedo operation when attacking a counter-torpedo capable submarine must include states that vary over time. A submarine ideally generates a jamming environment to evade the deadly weapon. Under a jamming condition, the torpedo might be blinded, causing it to return to search mode, at which point the torpedo again performs a helical search and is in a search state. The function of a decoy is to imitate a submarine signal; the decoy may catch the torpedo's attention, causing the torpedo to pursue the decoy instead of the target submarine until the fake identity of the decoy has been distinguished. While the torpedo is in pursuit of the decoy, the submarine gains additional time and escapes the danger