Effectiveness Analysis of Anti-torpedo Warfare Simulation for Evaluating Mix Strategies of Decoys and Jammers

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Abstract. Modeling and Simulation (M&S) engineering has been widely used for design and evaluation of underwater warfare systems. M&S engineering enables more efficient procurement of military equipment by analyzing these systems with simulations. This paper extends previous work, which used an anti-torpedo simulator with only decoys. To facilitate more diverse simulations of anti-torpedo combat, we design and add a simple jammer model, because the jammer is one of the most effective counter-measures against torpedo attacks. Utilizing this proposed model, we collect experimental data about the survivability of surface-ships that use anti-torpedo strategies and analyze the proper parameter values of jammers that satisfy the required Measure of Effectiveness (MOE). The experimental results show both the required performance of jammers and the efficiency of jammers with decoys. The results can be utilized to support the decision-making process for future equipment procurement.

1 Introduction

For the sake of developing weapon systems effectively, Modeling and Simulation (M&S) engineering has been widely employed for requirement analysis, development, test and evaluation, and weapon system training. M&S Engineering is an especially suitable approach for the weapon systems of vehicles designed for underwater warfare, such as a torpedo, a decoy or a submarine, because the factors of those vehicles have become more complicated and diversified. Applying M&S technique, Simulation-Based Acquisition (SBA) and development facilitate decisions about equipment procurements and tactics developments.

In past years, there have been some efforts to develop the underwater warfare simulation for academic purposes as well as commercial tools. For example some simulation tools, such as ODIN[1] and ORBIS[2], were developed for commercial uses, and some papers about simulation tools were published for academic purposes [3][4].

To contribute to these diverse efforts, this paper uses an anti-torpedo warfare simulator for developing the weapon systems of a surface ship [5]. This simulator is designed for an effectiveness analysis of weapon systems and uses Discrete EVent Specification (DEVS) formalism. By virtue of DEVS, the simulator can be extended with less cost, and the models of this simulator are reusable for various models.

In addition to the merits of DEVS formalism, it applies the collaborative modeling methodology [6]. This methodology decomposes the model into sub-models from a top-down perspective and partitions the sub-models into the two modeling levels of the object: discrete event-model (DEM) and detailed object model (OM). In the simulator, each platform is described as abstract DEM and has detailed OMs, which are algorithms for decision-making or calculation that involve domain-specific knowledge. Therefore, two different experts can develop their own models collaboratively.

This paper features extended content for evaluating mix strategies of decoys and jammers, whereas the existing simulator dealt with tactics of only decoys for counter-measures against a torpedo. The present study concentrates on jammers, as they are one of the most effective anti-torpedo counter-measures. Jammers generate air bubbles or noise to prevent the sonar of torpedoes from detecting our forces. While the jammer confuses the sonar of the opponents, the surface-ship can evade the opponents. In this paper, we introduce our design of a simple jammer model and revision of the simulator for mix strategies. We analyze the required parameter values of our jammer two-dimensionally for the sake of supporting the decision-making process for future equipment procurement.

This paper is organized as follows. Section 2 presents several of the related works and DEVS formalism. Section 3 explains the overall design and its additional components, and section 4 illustrates the effectiveness analysis with the experimental results from the anti-torpedo simulator with a jammer. Finally, section 5 concludes this paper.

2 Related Work

We firstly introduce surveyed papers about simulation tools of underwater warfare combat. Secondly, we briefly introduce the aspect of DEVS formalism that we apply to our modeling of the underwater warfare system in this paper.

2.1 Previous Research

In recent years, some efforts have been made to develop M&S techniques for underwater warfare. Among these efforts are two papers that deal with evaluating mix strategies of anti-torpedo combat including jammers.

One of them is by Cho et al. [3]. They developed all simulation models for an anti-torpedo simulation of submarines that uses DEVS formalism. By executing the simulation models in DEVSim++ [7], they examined maximum speed, acceleration and countermeasure systems capabilities. However, this research presents a disadvantage in that it is difficult to apply to other tests of candidate tactics of underwater platforms due to the low reusability of their study's models. This research is the most similar to the present paper with the difference that Cho et al. focused on submarine evasion, not surface-ship evasion.

Another study similar to our own is Liang and Wang's study [4]. This study included candidate tactics of underwater platforms. Unlike our study, Liang and Wang did not base their study on mathematical formalism. Consequently, complicated model development or functional extension of existing models was restricted in their study, and the cost of these works was expensive.

2.2 DEVS formalism

The DEVS formalism, which is a set of theoretic formalisms, specifies a discrete event system in a hierarchical and modular form [8]. The DEVS formalism provides the framework for modeling, and its framework has several modeling advantages, such as completeness, verifiability, extensibility, reusability and maintainability. In addition to these advantages, the formalism is known to be compatible with the object-oriented view. The modeler can specify a system easily by decomposing a large system into smaller component models.

The DEVS formalism consists of two types of models, coupled models and atomic models. The coupled model provides the method of assembly of several atomic and/or coupled models, and the atomic model describes the basic behavior of models.

3 Model Design

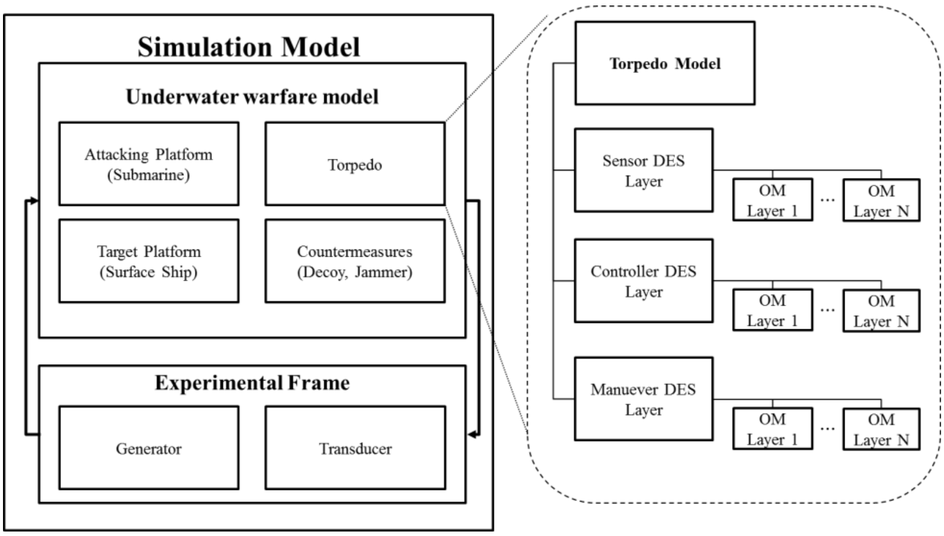

Fig. 1. Overall model design and an example model (a torpedo model) [5].

The existing model is designed based on DEVS formalism. This paper adds a simple jammer model to the existing overall model. In this section, we provide an overview of model design and describe the model of the jammer as well as revisions of other models.

3.1 Overall Model Design

The existing model design is depicted in Figure 1. The whole simulation model consists of an underwater warfare model and an experimental frame; the underwater warfare model simulates the combat systems and the experimental frame is a controller of the underwater warfare model for analysis.

Each underwater warfare model consists of 3 DES layers: Sensor, Controller and Maneuver. Each layer has object models for detailed behaviors. As we mentioned, this simulation model offers a high degree of flexibility and reusability on account of these model structures.

3.2 Design of Added Component

A jammer is the underwater device that makes underwater noise or air bubbles for masking the sound of underwater vehicles during the performance of evasion maneuvers [8][9]. We design this jammer as a simple DEVS model to offer a new countermeasure component and to extend the objective strategies of the previous model. The behavior of our jammer model is simple. After the jammer is fired and is settled on the proper position, it sends jamming signals to a sensor model of the torpedo. As a result, the sensor of the torpedo cannot detect the target while its sensor is being attacked by the jamming signal.

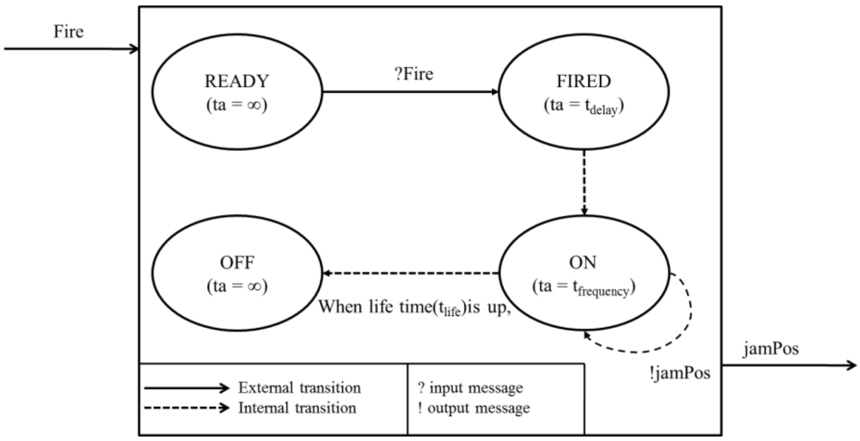

Fig. 2. Design of the jammer model (t_{delay} is the time of the firing delay. $t_{frequency}$ is the interval time required to send output messages. t_{life} is the total lifetime of the jammer).

Figure 2 demonstrates that the new jammer model has a simple design. In its initial state, 'READY', the controller of the surface ship orders 'Fire'. Then, the jammer is launched to a proper position on the surface of the water during t_{delay}. The next state after 'FIRED' is the 'ON' state. During the 'ON' state, the jammer transmits the jamming signals to the 'jamPos' port periodically. When the jammer's lifetime is up, the jammer seizes up.

It is the torpedo model's role to decide whether the jamming signal is effective or not. After receiving messages regarding the positions of the jammer, the torpedo's sensor makes a decision by using some parameter values. If the signals turn out to be effective signals, the torpedo's sensor ignores the renewal of position message that comes from the other underwater warfare model.

There are two object models in the jammer model. One model organizes the decision process regarding the effectiveness of the jamming signals. Effectiveness is determined only according to the distance between the jammer and the torpedo with no consideration of the particular frequency band involved. The other model shows how to launch the jammer in a proper position, and the position of the jammer is simply fixed to a short distance in front of the surface-ship.

The processes in this paper are simple but they are performed in a detailed object model, not in the DEVS model. When a more complex jammer is needed, these functions of the jammer are readily changeable.

4 Case Study - Anti-torpedo Warfare Simulator

All DES layers and experimental frame models are implemented with the DEVSim++ library, which is a DEVS execution environment that uses C++ by SMSLab in KAIST [7]. The rest of the simulation models, which are the object models representing detailed functions, are implanted in C++ language. The shared library technique ensures the effectiveness of these functions.

This section illustrates the developed simulator, which is an extended anti-torpedo simulator for effectiveness analysis that has a new jammer model. By analyzing the survivability of the surface-ship on diverse parameter values and tactics, we show how we gather insights for equipment procurements and tactics development by the simulator.

4.1 Torpedo Engagement

The attacking platform is a submarine and the target platform is a surface ship. The latter uses jammers and decoys for counter-measures. The brief scenario is illustrated in Figure 3. The surface-ship launches counter-measures (decoys and jammers) according to stored strategies against the torpedo's possible paths.

The objective of the experiment is to measure the survivability of the surface-ship as our new jammer model's MOE (Measure of Effectiveness). By changing the parameter of the jammer repeatedly, we analyze the survivability of the ship to support the decision making process for future equipment procurements.

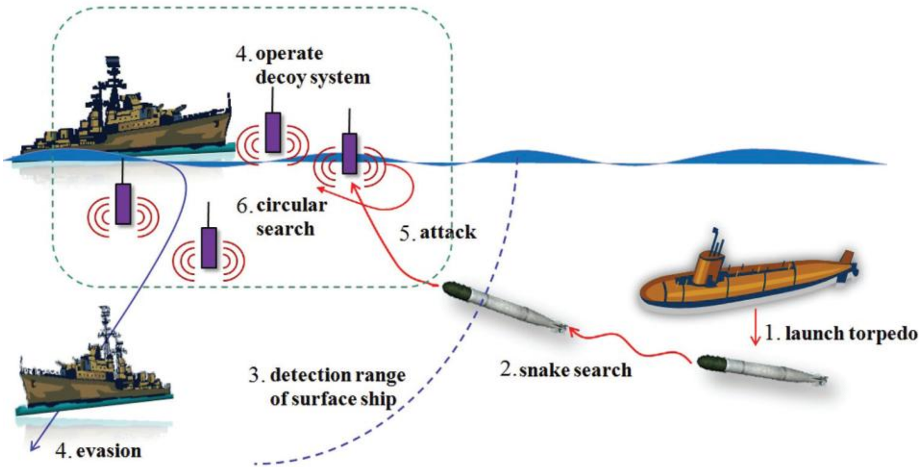

Fig. 3. Brief scenario of anti-torpedo warfare.

Table 1 lists the major parameters for the jammer model in this paper. Parameters of other simulation models are listed in our previous paper [5].

Table 1. Major parameters for the jammer model.

Parameter name	Default value	Implications
Lifetime	250s	Time period from launch to expiration
Jammed range	2500m	The range of the jamming effect
Reliability	90%	The probability of working normally

4.2 Experimental Results

We performed two experiments to analyze MOE using this extended simulator. The main purpose of these experiments is to discover the parameter pairs that satisfy required MOE. At first, we compare the survivability of the extended simulator to experimental results of our previous work. Choosing one example strategy from this result, we executed the simulator repeatedly by changing the parameters of the jammer model.

Table 2. Four patterns of the decoy operating system from the previous work [5].

Pattern#	Implications
1	4 static decoys (2 decoys at the front of surface ship and the others at the rear)
2	4 mobile decoys (2 decoys at the front of surface ship and the others at the rear)
3	2 static decoys at the front of surface-ship and 2 mobile decoys at rear
4	2 mobile decoys at the front of surface-ship and 2 static decoys at rear

The first experiment tests four patterns of counter-measures by using decoys. Table 2 shows detailed information of the patterns. We add a jammer to these four patterns and conduct 100 simulations of each mix strategy.

Table 3 shows the experimental results about the first experiment, comparing survivability of extended simulator to previous work.

Table 3. Results from the first experiment.

Pattern #	1	2	3	4
Only decoys	7	32	46	3
Decoys with jammer A Lifetime = 200s, Jamming Range = 1500m	10	61	70	59
Decoys with jammer B Lifetime = 300s, Jamming Range = 2500m	91	78	81	78

The first row shows the results of the strategies that have only decoys. The rest of the table shows the results of the strategies with an added jammer. A comparison of the first row with the others shows that the survivability of the surface-ship is better with new counter-measure, the jammer. The increases in the survivability of the first pattern and the fourth pattern are the most dramatic. As a result, we can conclude that a jammer is a good option for anti-torpedo counter-measures in patterns 1 and 4.

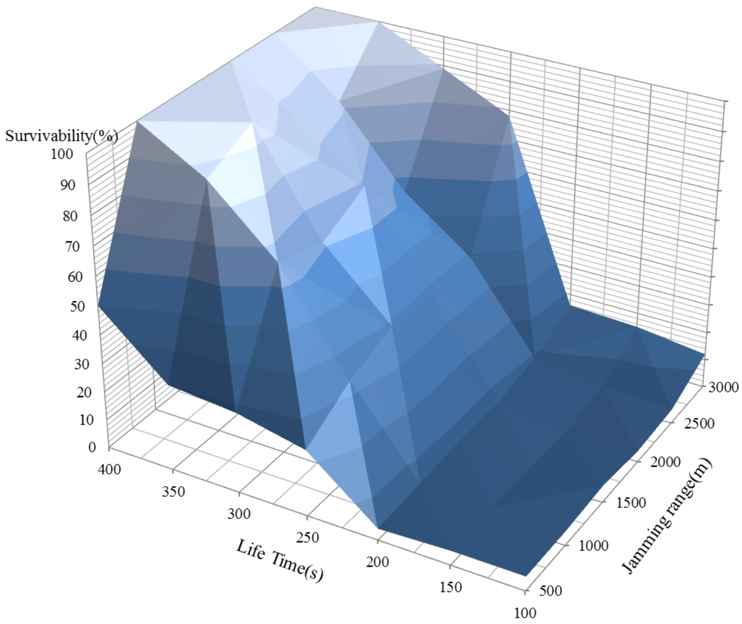

Fig. 4 Experimental result of survivability of the first pattern with a jammer.

From the above result, we choose one example strategy to collect data for procurements. We chose pattern 1, because the survivability of pattern 1 increased considerably whenever pattern 1 was given an additional jammer. Figure 4 is a 3-dimensional graph that represents the survivability of pattern 1 with a jammer according to lifetime and jamming range.

This graph shows that survivability becomes better as the values of the parameters increase. Since one purpose of this experiment is to determine the parameters that satisfy the required MOE, we redraw this graph 2-dimensionally from the top of this 3d graph, and we set up 80% as the required MOE.

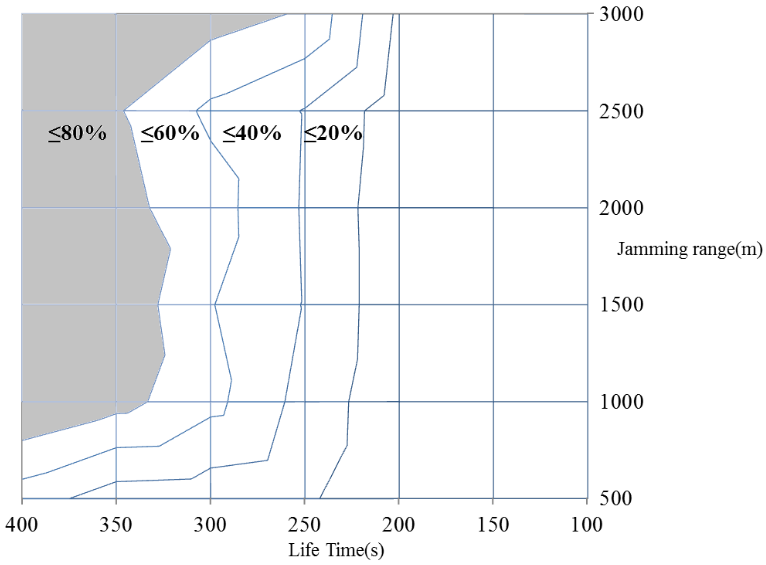

Fig. 5. Two-dimensional redrawn graph of Fig. 4.

The gray territory of Figure 5 satisfies the required MOE. Thus, we can gather proper pairs of parameters that satisfy the required MOE: (300, 3000), (350, 1500 ~ 3000), (400, 1000 ~ 4000). In addition, we can obtain one more insight: when the lifetime of a jammer is over 350, the strategy of the counter-measure is effective regardless of the jamming range.

If experiments for other patterns or new patterns with different values are conducted, we could gain the proper parameter values from the above analysis.

5 Conclusion

This paper proposes an anti-torpedo simulator with a simple jammer model to analyze the MOE of more diverse counter-measures. We have successfully gathered knowledge supporting the procurement process of jammers and can continue to do so through analyzing survivability with this simulator.

Although an evident weakness of this simulator is that our jammer model is extremely simple and not based on real specifications, military experts can nevertheless apply this simulator and analysis methodology to real jammer models, because our jammer model offers a detailed and changeable object model. Future work should consider the addition of more complex jammer models.

Acknowledgement

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