Predicting the Operational Effectiveness of Aircraft Survivability Equipment Suite

Sanguk Noh and Chaetaek Choi

***Abstract*—In this paper, we model the method in which aircraft survivability equipment suitessuccessfully choose their countermeasures, and experiment with their autonomous decision-making against threats in various electronic warfare settings. We have designed and implemented our simulators to estimate the operational effectiveness of the aircraft survivability equipment suite. We formulate the operational effectiveness into the form of reduction in lethality, and also propose the benchmark of reduction in lethality in various methods of removing threats. Using our simulator, we hope that the autonomous decision-making of countermeasures and the analysis of survivability using the framework of reduction in lethality could be available for military operators.**

***Index Terms*—Autonomous decision-making, electronic warfare settings, aircraft survivability equipment suite, operational effectiveness**

I. Introduction

In order to counter threats in electronic warfare environments, a command and control agent within an aircraft survivability equipment (ASE) suite needs to detect, classify, and autonomously execute countermeasures against such threats for ensuring continual functionality despite potential danger. In our previous work [1], we proposed a threat detection and classificationmechanism through soft computing algorithms. Thesesoft computing algorithms compile the instances of the threat system and their attributes into a set of reactive rules. Our approach allows us to model threat systems in battlefield situations, and avoids critical situations which might be irrevocable.

Given the battlefield situation at hand,further, the next step is to equip our command and control agent with the ability to dynamically and rationally select countermeasures against threats. In this paper, our agent will follow the decision theory [2], which calculates the expected utilities of alternatives. The agents will finally succeed in completing their tasks by executing the best countermeasure, which has the maximum expected utility. Since the properties of electronic warfare environments are unforeseen, partially accessible, and continuously changing, the protocol-based approaches could not be applied to our setting. Applying the decision theory to selecting the countermeasures at military scenarios might be the first attempt to our best knowledge, and it might be a robust approach in battlefield situations.

To test the operational effectiveness of the aircraft survivability equipment suite, we formulate the operational effectiveness into the form of reduction in lethality (RL), and also propose the benchmark of RL in various methods of removing threats. We have designed and implemented our simulator to estimate the operational effectiveness of the ASE suite. We will present the experimental results for the autonomous decision-making of countermeasures and the analysis of aircraft survivability.

Manuscript received May 15, 2012; revised June 20, 2012.

Sanguk Noh is with School of Computer Science and Information Engineering,The Catholic University of Korea, Republic of Kore(email:sunoh@catholic.ac.kr).

Chaetaek Choi is with the Agency for Defense Development, Republic of Korea.

II. Aircraft Survivability Equipment Suite

A. Autonomously Deciding Countermeasure

To be rational in a decision-theoretic sense, the agents follow the principle of maximum expected utility (PMEU) [2]. We will show how PMEU can be implemented in the decision-making process of the selection of countermeasures under uncertainty. Our agents equipped with PMEU will select the most appropriate countermeasure to effectively remove threats.

We will use the following notation:

- a set of agents: $N = \{n_1, n_2, \ldots\}$;
- a set of actions of agent n_i, $n_i \in N$: $An_i = \{a_i^1, a_i^2, \ldots\}$;
- a set of possible world states: $S = \{s_1, s_2, \ldots\}$.

The expected utility of the best action, α, of agentn_i, arrived at using the body of information E, and executed at time$t$,is given by

$$EU(\alpha \mid E,t) = \max_{a_i^j \in A_{ni}} \sum_k P(s_k|E,t,a_i^j)U(s_k) \quad (1)$$

where

- $P(s_k|E,t,a_i^j)$is the probability that a states_k willobtain after action a_i^j is executed at time t, given the body ofinformation E;
- $U(s_k)$is the utility of the state s_k.

For the purpose of formalizing the decision-making problem of selecting countermeasures against threats, we should model probabilities and utilities in Eq. (1). In our model, for example, the probability that a countermeasure would be successful is assumed to depend on jamming signal power, useful signal power reflected, and so on, when jamming countermeasures are executed. The utility that denotes the desirability of a resulting state after a countermeasure is executed can be assigned by a single number considering the type of receivers.

B. Operational Effectiveness

To predict the operational effectiveness of an aircraft survivability equipment (ASE) suite, we formally define the accumulative reduction in lethality (RL) as the decreased amount of the percentage that aircrafts are going to be shot by the threats, when the ASE suite could use countermeasures against threats (this is called as a term 'WET') compared with when it couldn't use them (this corresponds to a term 'DRY').

Let's define the following basic terms. The number of shots is the total number of threats that an aircraft is encountered. The number of hits is the number of threats that might kill the aircraft. In this case, the kill may mean if the aircraft is positioned atwithin a weapon (missile threat) lethal radius. The probability of kill while DRY mode, $P_{K_{DRY}}$, and similarly, the probability of kill while WET mode, $P_{K_{WET}}$, can be defined using the following equations (2) and (3), respectively:

$$P_{K_{DRY}} = \frac{the\ number\ of\ Hits_{DRY}}{the\ number\ of\ Shots_{DRY}} \quad (2)$$

$$P_{K_{WET}} = \frac{the\ number\ of\ Hits_{WET}}{the\ number\ of\ Shots_{WET}} \quad (3)$$

The accumulative reduction in lethality, then, should be defined as follows using equations (2) and (3):

$$R_L(\%) = \left(\frac{P_{K_{DRY}} - P_{K_{WET}}}{P_{K_{DRY}}}\right) \times 100\% \quad (4)$$

C. Experimental Results

The experiments in this section are designed to evaluate 1) the performances of the decision-making of countermeasures against threats, and 2) those of its operational effectiveness. In the first experiment, we measure the decision-theoretic agent's performance in terms of the sum of expected utilities of the best countermeasures selected given a situation. In the second experiment, we also measure the accumulative reduction in lethality, i.e., the ratio of survivability, when the aircraft survivability equipment suites use countermeasures to attacking threats.

To evaluate the quality of the decision-making process of countermeasures against threats in electronic warfare settings, the resulting performance is expressed in terms of the cumulative expected utilities. The cumulative expected utilities in this experiment are summarized in Fig. 1.as the sum of expected utilities after 200 selections of countermeasures have been made.

In this experiment, the strategies for the selection of countermeasures are as follows:

- αstrategy: the selection of the countermeasure that has the highest expected utility;
- βstrategy: the selection of the countermeasure that has the highest probability representing its successfulness, when it is executed;
- γstrategy: the random selection of the countermeasure.

As we expected, in Fig. 1, the performance achieved by our agents following decision theory (αstrategy) was better than that of the agent guided by the random selection strategy (γstrategy). The performance of the agent with β strategy representedthe worst among them. Compared with the performance of the random agent, the performanceof our agent was increased by 12%.

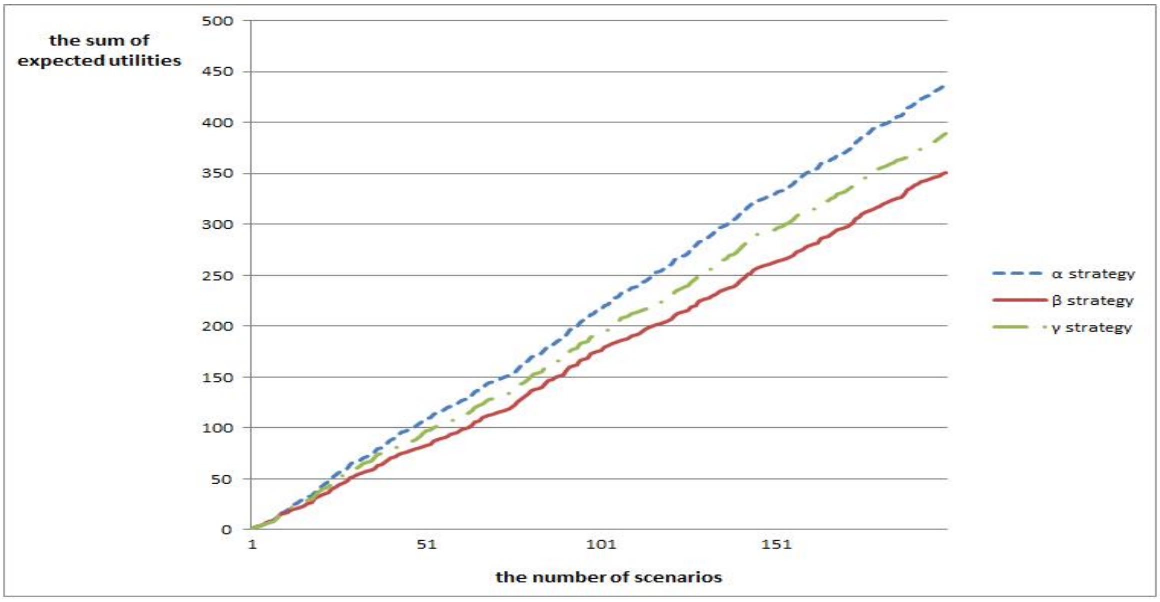

Fig. 1. The resulting performances using the α, β, and γ strategies, respectively

The second experiment is to estimate the operational effectiveness of aircraft survivability equipment (ASE) suite, which represents how effectively the decision-making of countermeasures are made. Towards this end, the accumulative reduction in lethality (RL) was measured, as the command and control agent within the ASE suite removed incoming missile threats. The RL simulator consists of the simulation setting and the resulting values, as depicted in Fig. 2, and the display of reduction in lethality, as depicted in Fig. 3.

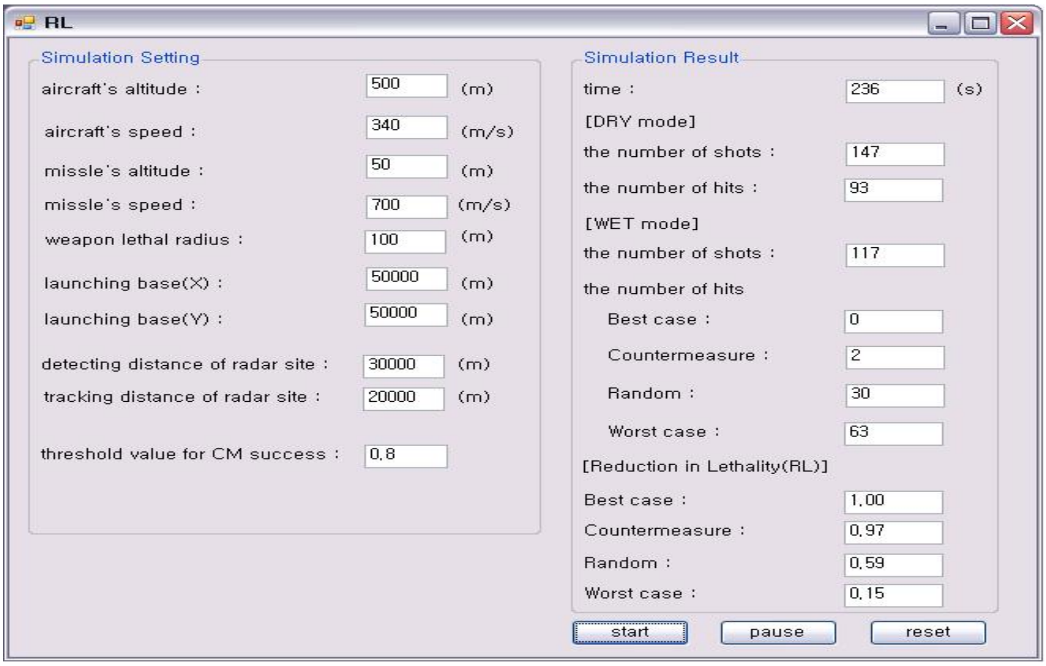

Fig. 2. RL simulator – the simulation setting and the resulting values.

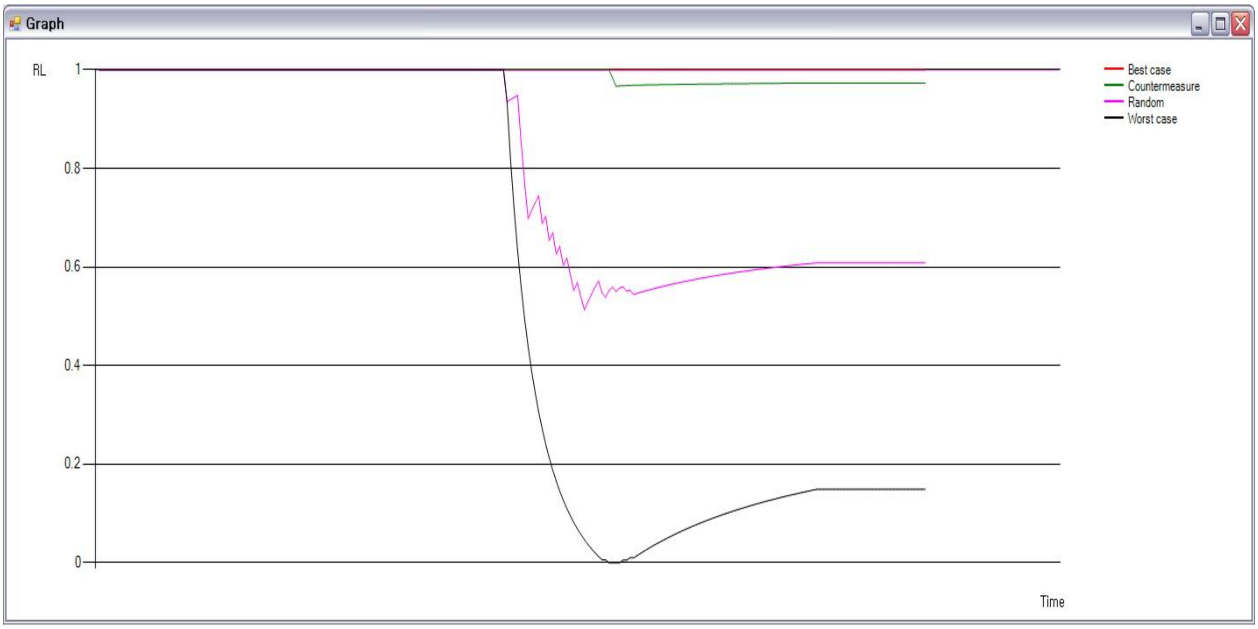

Fig. 3. RL simulator – the display of reduction in lethality.

In the simulation setting part of our simulator, from aircraft's perspective, its initial position and average speed could be input, and, from missile threat's perspective, its launching position, average speed, valid tracking distance, and weapon lethal radius could be set during the simulation preparation mode. In the display of RL, as depicted in Fig. 3, the RL simulator displays the four RL percentages depending upon how command and control agents within the ASE suite remove their missile threats. The four RL percentages are as follows:

- RL_{Best}: when the agents remove all of threats using their countermeasures;
- RL_{Worst}: when the agents cannot remove any incoming threat;
- RL_{Random}: when the agents randomly remove threats using their countermeasures;
- RL_{CM}: when the agents can remove threats if theprobability that countermeasures are successful against threatsis over a certain threshold value, for instance, 0.80.

In a specific simulation setting, as shown in Fig. 2, the resulting RL's measured by using the above four strategies were summarized in Fig. 3. In Fig. 3, *x* axis represents time passed, since the simulation has started, and *y* axis presents the accumulative RL, i.e., the survivability ratio of an aircraft. In case of RL_{Best}, the RL was maximized, since the agents could remove all of threats using their countermeasures. However, in case of RL_{Worst}, the RL was minimized and the survivability ratio became 0, because of their inability to remove threats, when the time steps were 146. When the agents were assumed to remove only 50% of missile threats, namely, RL_{Random}, the accumulative RL was 0.5 at 138 time steps, was decreased into 0.48, and was increased up to 0.61. When the agents within the ASE suite could remove threats if the probability of success of their countermeasures was over 80%, the accumulative RL value was 97%.

III. Conclusion

In time-critical settings, autonomous agents need to quickly recognize a given situation, and to rationally react to it. Our work contributes to situation awareness, when robust autonomy is crucial. In this paper, we present a fully autonomous aircraft survivability equipment suite in electronic warfare settings. We showed the selection of alternative countermeasures against threats, and tested its operational effectiveness in various simulated settings.To be rational in dynamic electronic warfare settings, our agents were capable of choosing and executing countermeasures to threats, as maximizing their expected utilities.

We tested our agent's performance in simulated electronic warfare settings. The threat data in these settings were generated using discrete uniform, Gaussian, and exponential distributions, which got closer to real threats. The experiments revealed that the computation of the expected utilities made our agents rationally operational in dynamic battlefield environments. To evaluate our agent's operational effectiveness, then, we have designed and implemented a simulated test-bed, estimated our agent's reduction in lethality given a specific scenario, and presented the percentage of survivability in a graph.

As part of our ongoing work, we are performing a set of experiments with all possible configurations of threat systems, and are implementing a fully autonomous electronic warfare simulator. We will integrate various threat systems into a unified battlefield scenario and continuously test our agent's rationality with a tapestry of scenarios. We hope to be able to successfully remove threats through our future work, to precisely estimateits operational effectiveness, and for military operators to repeatedly use our framework in simulated electronic warfare settings in order to improve their survivability in real situations.

Acknowledgements

This work has been supported by the Agency for Defense Development, Korea, under Grant UD110079ED "A Study on Prediction of Aircraft Survivability Equipment (ASE) Suite Operational Effectiveness," 2011. We would like to thank our student, Kyuseon Lee, for his help in implementing and experimenting with the ASE suite simulator.

References

[1] S. R. Park and S. Noh, "Optimal Decision-Making of Countermeasures by Estimating Their Expected Utilities," *IEICE Transactions on Information and Systems*, vol. E93-D, no. 3, pp. 560-568, March 2010.

[2] S. J. Russell and P. Norvig, "Artificial Intelligence: A Modern Approach," *2nd Edition*, Chapters 13-17, Prentice-Hall, Englewood Cliffs, New Jersey, 2003.