A Frigate Movement Survival Agent-Based Approach *

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Abstract The position of a frigate to face some threats can augment its survival chances and therefore it is important to investigate this aspect in order to determine how a frigate can position itself during an attack. To achieve that, we propose a first method based on the Bayesian movement, performed by a learning agent, which determines the optimal positioning of the frigate by dividing the defense area into six sectors for weapon engagement and then, it makes efficient use of all the weapons available by using the sectors. The second method that we propose is called Radar Cross-Section Reduction (RCSR) movement and, it aims at reducing the exposed surface of the frigate to incoming threats before their locking phase is over. Preliminary results on these two methods are presented and discussed. Finally, an implementation of a meta-level agent which would make efficient use of both complementary methods is suggested.

1 Introduction

Maritimes operations are known to be very complex. In this context, a ship's Commanding Officer needs to set his team and his resources to maximum efficiency while running decisions from routines to high reaction and deliberation levels where he is in face to multi-threat situations. It is very important that he should be ready for all eventualities, keeping in mind that his ship should survive with the least damage if possible.

During the last decades, operational crews were trained to a sufficient level in order to operate within a force command structure where they can (1) recognize a threat, (2) know how to react to that threat and, (3) employ measures to defeat that threat. Unfortunately, nowadays systems, threats, measures and countermeasures, are becoming very sophisticated and it has became very hard to deal with any anti-air warfare. One can think to some team restructure and more efficient task allocation but although this allows more effective load sharing, it does not remove the load task work on the back of the Commanding Officer

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who remains with an increasing amount of information, particularly when comes the time to make decision in complex time critical situations. To counter these problems, research is ongoing in our group to design and implement resource management decision aids, based on intelligent agent technology. A key element of the defence process is determining ownship maneuvers.

In this paper, we present two movements. Firstly, the Bayesian approach offers the most effective combination of hardkill and softkill weapons to deal with threats. Secondly, the Radar Cross-Section Reduction (RCSR) movement aims at reducing the exposed surface of the frigate against incoming threats before their locking phase is over. Since the locking phase of a threat is usually used early and the defense of the frigate usually is at a later time, these two movements can be used in a complementary way. To this end, we propose a meta-level agent to effectively use both movements against incoming threats depending of the situation.

2 The Bayesian Approach

As a guideline, we assume that it takes at least a minute to turn the frigate by 180 degrees. It is extremely probable that such a maneuver will not be necessary because the various zones being able to influence the displacement of the frigate are symmetrical. On the other hand, the frigate does not merely rotate on a point when it turns. We assume it turns by moving through an arc with a turning radius of 270 meters, when the frigate does turn 180 degrees. We can consequently use fractions of these numbers when displacements are smaller.

2.1 Determination of the Effective and Overlapping Areas (or Sectors) of Individual Weapons

The determination of the effective areas of individual weapons and their overlapping areas can be done in terms of the angles that discriminate the different engagement capabilities of hardkill and softkill weapons. To find the optimal positioning of the frigate, the environment can be divided into twelve sectors[1] surrounding the frigate based on the hardkill and softkill engagement possibilities. These sectors will have to move along with the frigate, and maintain the same relative orientation to the frigate. Table 1 describes these twelve distinct sectors, showing the angular coverage of a sector and the difference in the weapon engagement capabilities of a sector compared to the "normal state". The Normal state at any time has: (1) one STIR available for a SAM, (2) a Gun engagement, (3) a CIWS able to engage threats, (4) a possible jamming engagement and, (5) chaff available.

All the sectors in Table 1 that have the same state (as indicated in the "Difference from Normal State" column), can be amalgamated to form a new representation of the sectors: (1) New Sector 1 = Sectors A + G, (2) New Sector

[1] This number covers all changes that we can detect around a frigate.

Sector	Angles	Difference from Normal State
A	330 to 30 °	One additional STIR
B	30 to 75 °	No difference — Normal State
C	75 to 80 °	No CIWS
D	80 to 100 °	No CIWS,but one additional jamming engagement possible
E	100 to 105 °	No CIWS
F	105 to 150 °	No difference — Normal State
G	150 to 210 °	One additional STIR
H	210 to 235 °	No difference — Normal State
I	235 to 260 °	No Gun
J	260 to 280 °	No Gun, but one additional jamming engagement possible
K	280 to 305 °	No Gun
L	305 to 330 °	No difference — Normal State

Table1. Description of the effective sectors for hardkill and softkill weapon engagements.

2 = Sectors B + F + H + L, (3) New Sector 3 = Sectors C + E
(4) New Sector 4 = Sector D, (5) New Sector 5 = Sectors I + K, (6) New Sector 6 = Sector J.

This establishes six distinct sectors, for which a succession of tests were conducted to determine their respective effectiveness. The effectiveness of each sector was determined using varying numbers of threats at short, intermediate and long ranges, under various planning modes of defense. The effectiveness was specified as the probability to kill a threat in a sector. With these measures of effectiveness for the various sectors, it was possible to estimate the optimal positioning of the frigate using the Bayesian [1] method discussed in next section.

2.2 Determining Frigate Maneuvers

It is very significant to have a robust method to modify the positioning of the frigate. If we detect at a given time during the elaboration of a plan an advantage for re-positioning the frigate to add an engagement, we should not simply add this engagement to the plan and move the frigate. We must have a much more robust method than this shallow approach. Such method is based on the following constat: Liang [3] suggests four regions of effectiveness for a frigate: i) a region where both hardkill and softkill are effective; ii) a region where only hardkill is effective; iii) a region where only softkill is effective; and iv) a region where neither hardkill nor softkill is effective. In these conditions, the defence system will try to have the maximum number of targets in the area where both are effective, and as few as possible in the area where neither is effective. Although this can increase the chance of weapon interaction, it is in area where both are effective that the frigate will have the most chance of survival.

We should therefore propose a method that considers all these facts. In fact, we do not try to directly put the maximum number of threats in the both-effective area and the minimum in the neither-effective area. We use a more complex and effective method, which intend to maximize the average probability of killing all threats, by turning the frigate in the “right” position.

This method uses a learning agent and it is important to note that the construction of the learning agent is a delicate problem. Thus, at the time of learning, we will have to find a method, which supposes that the frigate turns at an infinite speed. It is necessary to make this assumption to avoid falling into local optima, in other words, to not be able to go to the right position because of the speed constraint of the frigate. It is very probable that the frigate will not have time to effectuate a 180 degrees turn to modify its position to defend itself. We want to find which is the best position for the frigate at the time of learning according to certain threats and not being influenced by the actual position of the frigate.

Turn now to our naïve Bayes classifier. A particular position for the frigate is chosen over another using the Bayesian method. This method has been adopted because:

- It provides a solution for the evaluation of the position of the frigate in the forms of probabilities. Thus, each position of frigate will have its own chances of success and therefore it will be easier to compare the effectiveness of each suggested position.
- Under certain conditions, it provides a solution that is comparable to neural networks or a decision tree.

Naïve Bayes classifier gives:

$$v_{NB} = arg \max_{v_j \in V} P(v_j) \prod_i P(a_i|v_j) \tag{1}$$

In this equation, v_{NB} denotes the target value output by the naïve Bayes classifier. In this method, the number of distinct $P(a_i|v_j)$ terms that must be estimated from the training data is just the number of distinct attributes values multiplied by the number of distinct target values. So V is the finite set of values that an attribute a can take.

This method can apply very well to determine the optimal position that the frigate must have when is attacked by one or more missiles. We will explain what the various terms of the method means for our problem:

- V is the group of possible positions that the frigate can take.
- $P(v_j)$ is the number of times that a position is retained compared to the ensemble of the possible positions. At the time of learning, the threats come at a random direction towards the frigate. So the probability that a threat comes from a certain angle is the same from another angle. Thus, we can consider this term as a constant and by this fact, we should ignore it.
- $P(a_i|v_j)$ represents the probability of defending itself from a certain threat when the frigate has a certain position. $P(ASM\ \#2|\ 15\ degrees) = .85$ means that the frigate has 85% of chance to survive missile #2 when it is at the 15 degrees position. The percentage of survival is given by the learning agent.

So for this method to give a Maximum At Posteriori (MAP) hypothesis, it is necessary that different attribute values (a_i), which is a radius of an ASM, are conditionally independent, given the target value (v_j), which is a new positioning for the frigate. Therefore, it is necessary that the various ASMs angles are independent from the positioning of the frigate at priori. This is obviously the case because the frigate was not moving at all before. So an ASM angle doesn't influence directly the frigate's positioning just like for example: storm and thunder would not give a MAP hypothesis because a storm can directly create thunder.

2.3 Experiments

To experiment the frigate's positioning, we implemented the naïve Bayesian classifier, previously introduced. Each testing attributes were tested 20 times for number of threats varying from 1 to 15. So we made 300 (20 $\times$ 15) tests per testing attribute. Some of the results having the form $x \pm y$, which means that we have 95% of chance to obtain the same results within the range $x - y$ to $x + y$ if we remake the experiment. We used a probability of destruction of 50% for the frigate in the event of an impact of a threat.

Table 2 summarizes the learning (percentage of defence efficiency) made for the different sectors. In this table we can see that each sectors have different effectiveness. The sector 1 where we have 2 STIRs illuminators available is the best for the frigate to defend itself (93,6%). However, the sector 3 where we can't use the CIWS is the less effective area for the frigate to defend itself (82,5%). In our case, the Bayesian algorithm makes a product probability to kill all threats in a scenario using these numbers depending on the orientation and the number of threats.

Figure 1 shows that frigate has more chance to survive with positioning that without positioning. However, when the number of threats become high, this advantage becomes less apparent because frigate has less time to address all threats.

Sector → threat(s) per scenario ↓	1	2	3	4	5	6
1 to 3	100 ±0,0	95,8 ±3,6	94,2 ±4,2	94,2 ±4,2	97,5 ±2,5	95,8 ±3,6
4 to 6	96,7 ±2,0	94,0 ±2,7	92,0 ±3,1	91,0 ±3,5	91,0 ±3,2	92,7 ±2,9
7 to 9	95,6 ±1,8	91,9 ±2,4	80,4 ±3,6	92,7 ±2,8	89,0 ±2,8	90,0 ±2,7
10 to 12	92,4 ±2,0	87,7 ±2,5	80,2 ±3,0	85,6 ±2,7	88,0 ±2,5	87,6 ±2,5
13 to 15	91,3 ±1,9	83,2 ±2,5	80,5 ±2,7	84,0 ±2,5	85,5 ±2,4	86,9 ±2,3
Overall	**93,6 ±1,0**	**88,2 ±1,3**	**82,5 ±1,5**	**86,5 ±1,4**	**88,2 ±1,3**	**88,9 ±1,3**

Table2. Learning made by our algorithm.

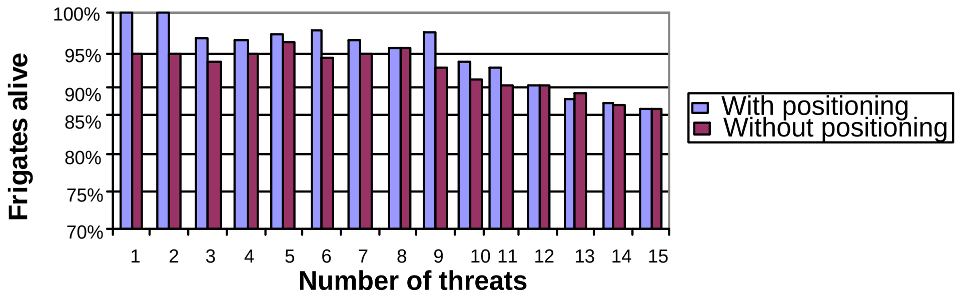

Figure1. Results with and without frigate's positioning under our planning algorithm.

	Results
General efficiency without positioning	90,9% ±1,2
General efficiency with positioning	92,1% ±1,1
Improvement	1,2%
Improvement to 100%	13,19%

Table3. Results with and without frigate's positioning.

3 The Radar Cross-Section reduction Movement

The Radar Cross-Section Reduction (RCSR) movement aims at reducing the frigate's radar cross-section exposed to incoming threats. As the capability of threats to lock onto the frigate is directly related to the radar cross-section of the frigate [3], [4] they see. Thus, an appropriate frigate position makes it considerably harder for threats to lock and keep a lock on the frigate.

In our case, the study of the RCSR was done in three phases. The first one is to implement an algorithm which minimizes the surface exposed for all the threats by planning one or more positioning movements. In this part, we position the frigate in an optimal way by considering only the angle to which the missile will impact the frigate. In the second part, we add a constraint over the available time to effectuate the movements. It is thus necessary to effectuate the same type of movement, but before the missile is locked on the frigate. The algorithm remains the same, but the response time is reduced. The last phase presented in the next section consists in implementing an agent which uses this movement, combined in time, with the other developed movements (Bayesian Movement). Thus, we want a movement allowing an optimal use of the resources as well as a reduction in the threats engaged on the frigate.

We will discuss here the work completed on the first phase, which is the implementation of a movement aiming at reducing the exposed surface of the frigate. This is the *Damage Reduction movement* (*DR movement*).

We used a probability of destruction of 50% for the frigate in the event of an impact of a threat. For the purpose of development of the algorithm, we made a voluntary simplification and supposed that this probability was proportional to the exposed surface to the threat at the time of impact with the frigate. For exposed surface, we used simplified frigate structure as illustrated in figures 2 and 3.

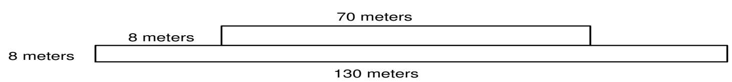

Figure2. Frigate's side view.

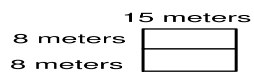

Figure3. Frigate's front view.

If the frigate is on the side, we have an exposed surface which is maximum, that is to say approximately 1600 square meters. This situation corresponds to the maximum destruction probability of 50% stated earlier. If the threat is at the front (or rear), the exposed surface is minimal approximately $240\mathrm{m}^2$. This situation gives us a probability of destruction of 7.5%.

Usually, the frigate is turned to face each threat, if it has time. This algorithm thus produces a sequence of 1 to n positions, n being the number of threats.

In fact, we can propose a general formula expressing the survival rate for a frigate. The survival probability is the complement of the destruction probability, which is expressed by the following equation (note: $P(hit_i)$ and $P(kill_i|hit_i)$ in [0,1]).

$$P(survive_i) = 1 - P(hit_i) \times P(kill_i|hit_i) \tag{2}$$

For a scenario with n threats, the survival probability is expressed in the following way.

$$P(survive) = \prod_{i=1}^{i=n} P(survive_i) \tag{3}$$

Bayesian movement aims at diminishing $P(hit_i)$, so that it is less likely that a threat reaches the ship, but will have higher probability of destruction should it happen. On the other side, the implemented first stage of RCSR movement aims at reducing $P(kill_i|hit_i)$, so that it's more likely that a threat reaches ownship, but with less probability of destruction in case it happens.

So, if we compare the two movements, Bayesian movement positions the frigate to use resources efficiently to counter threats, while DR movement positions the same to reduce its exposed surface. Because of resources disposition on the frigate, the two movements give opposite results, as shown on Figure 4. With Bayesian movement, the frigate will move to meet the threat in the sector where it has the most resources available, being on the frigate's side, thus almost maximizing $P(kill_i|hit_i)$. The next section will talk about a meta-level agent which would decide the best movement to make depending on the situation — The Bayesian movement and the RCSR movement.

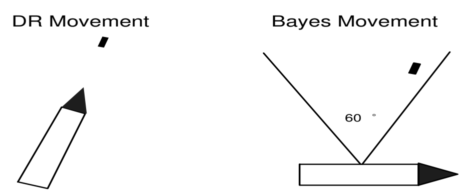

Figure4. Bayes and Damage Reduction movements.

4 Combining both Movements Using a Meta-Level Agent

As earlier stated, the Bayesian movement purpose is to augment the resource utilization of the frigate, while the RCSR movement purpose is to reduce the exposed surface for the frigate by a threat locking on ownship. We can see in figure 5 a general view of the time of utilization of these two movements.

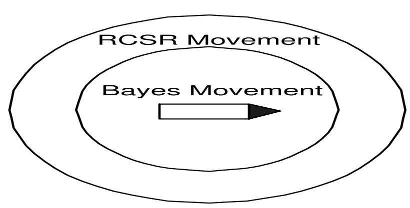

Figure5. Utilization of Bayesian and Damage Reduction movements.

We can see that the RCSR movement is generally made earlier that the Bayes movement. It is a more simple problem to effectively use these two movements if they have their respective area of coverage. But, it is not so simple, we have to make dubious reasoning to know if a threat is indeed locked on a frigate. Also, once a threat is locked, it will remain locked on the frigate and the only useful movement is the Bayesian one.

We suggest a meta-level agent [2] which evaluates the Bayesian and RCSR movements and suggests which one is the best in function of a given situation. To do that, this agent can look at the overall situation and choose to make Bayesian move on certain threats and RCSR movements on others. We estimate that a RCSR move is more effective mathematically than a Bayesian one. But, in our situation, we rank all threats from the most dangerous one to the least dangerous one. We have to define how to deal with the threat ranking attribute as well as the effectiveness to counter a threat, by manoeuvring. We will illustrate this problem with an example with two threats for which a threat is very near the frigate (threat #1), and another one is far away (threat #2). We find that a Bayesian move would augment the defense efficiency for the frigate of 1% on threat #1 and don't change our efficiency to counter threat #2 which has not locked yet. Also, a RCSR move would augment our chance of survival of 3% on threat #2 and stay the same for threat #1. In the general case, it is not simple to choose the right movement to do. Consequently, we have to establish an agent which would consider the survival difference of making a certain move on each threat.

We will investigate different alternatives to solve this problem. We could view it as a learning problem and resolve it for example with a neural network, or as an optimization problem and solve it for example as a constraint satisfactory problem (CSP).

5 Conclusion

The effectiveness of the frigate's weapons varies depending on the orientation of the frigate with respect to the threats attacking it. It also varies according to the surfaced exposed to threats which are at locking time. We developed two movements for addressing these two issues. Then, we discussed the use of a meta-level agent to effectively use both movements depending of the situation.

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