

Simulating ASW: Agent models and game theory

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Abstract — Successful anti-submarine warfare (ASW) operations require intelligent use of both platforms and sensors. In the real world this is accomplished through training and usage of highly skilled personnel, with the help of tactical decisions aids. Simulations of these operations will therefore also require intelligent decisions to be made in the virtual world by the simulated agents, though necessarily requiring them to be decided automatically by the simulation program. The difficulty of modelling these behaviours increases with the fidelity of the virtual environment, making striking the correct balance one of the main goals of any modelling endeavour.

In anti-submarine warfare operations, sonar remains the most important sensor class for detecting submarines under water. Modelling this in a realistic manner will require a high degree of fidelity in the virtual sonar environment, thus also requiring more complex decision-making processes for the simulated agents. By using an appropriate acoustic model, the agents can calculate the probability of detection based on relevant configurations and the current environment.

We demonstrate the possibilities of this approach with the anti-submarine warfare simulation framework Rattus, where the agents use game theory to intelligently pick their sonar depths to achieve superior performance. This gives the simulation results more credibility and weight for their use in evaluating the performance of both current and future systems. At the same time, by increasing the simulated environment fidelity, any intelligent decision-making processes developed for the simulations can be more easily adapted to real world operations, potentially providing decisive tactical advantages.

1 Introduction

Modern anti-submarine warfare (ASW) operations require the coordination of several units in order to conduct successful operations. Considering the problem of detecting an opposing submarine with sonar, the units consisting of different platforms and sensors need to intelligently use their capabilities in order to maximize their sensor coverage and probability of detection. In order to achieve this, the sonar operators on each unit need to leverage their available information about the current sonar environment. How to share this information among allied units and formulate complementary strategies is not obvious. Additionally, the advent of autonomous ASW platforms necessitates a formal and robust approach, which can function without the intervention of trained human operators.

2 Agents

Any autonomous problem-solving entity that reacts to its environment and acts in it in order to meet its objectives can be formally described as an *agent* [1]. This can apply to sonar operators that adjust sonar parameters and request new vessel courses in order to fulfil their objective of locating an opposing submarine, as well as integrated autonomous ASW platforms that attempt to solve the same task without human input. Any realistic simulation of ASW operations should therefore strive to implement the virtual ASW units as agents. The key to making an agent autonomous is allowing it to adapt to its environment, which involves the agent selecting its sonar parameters and

navigation in an intelligent manner in order to fulfil its objective. For sonar operations, this requires an appropriate acoustic model, in order to determine the detections probabilities in the given environment.

The searching ASW units should not be the only agents in such a simulation. The opposing submarines should also be implemented as agents, though with the opposite goal of *not* being detected while maintaining some passive sonar coverage of the surface. Because of this, the full operation can naturally be described as a *multi-agent system*, in which multiple intelligent agents interact while aiming to solve their objectives. Because the agents need to consider the strategies and choices of other agents when making their own choices, they will be engaging in *strategic interaction*. The predominant way to handle this formally is through *game theory* and the *Nash equilibrium* [2] solution concept. A Nash equilibrium is a set of strategies for all agents where no agent can expect a better outcome by changing only their own strategy, and this is therefore the expected behaviour for rational and intelligent agents.

3 Simulation method

In previous work [3], a game theoretical method for selecting sonar depths for ASW units and target depths for underwater platforms was formulated, based on the local sound speed profile, an acoustic model and the resulting Nash equilibrium. This method has been expanded for environments with varying sound speed profiles, wind speeds and bottom profiles for different times and positions [4], increasing the robustness of the distributions

for sonar and target depths with respect to environmental variability and uncertainty. They are distributions in the sense that the recommended strategy is not a single depth, but a probability weighted selection of several depths. The performance of these intelligent ASW strategies is evaluated using an ASW simulation framework, Rattus [5].

Each simulation will start the submarine in a random position 25 km away from a static ASW platform equipped with an active variable depth sonar. The sound speed profile and wind is sampled from a random position and time in the area in a span of 5 days. The probability of detection for each ping is evaluated using the current bottom profile toward the submarine, using the acoustic ray-tracing model Lybin implemented in Rattus [6]. The submarine will pick a constant course with the initial bearing toward the ASW unit being between 15° and 45° . The simulation halts if the submarine exits the 25 km radius area or if the submarine is detected in 3 out of 4 consecutive pings, causing a track to initiate. The simulation setup is sketched in figure 1.

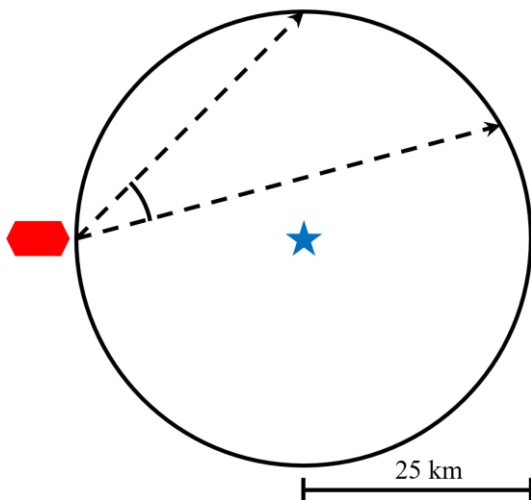


Fig. 1. The simulation setup, with the submarine in red and the ASW platform in blue. The constant course the submarine traverses the area is randomly sampled between 15° and 45° , shown with the dashed lines.

Three different sonar and target depth selection strategies are investigated: static depths, depths sampled from the 5-day aggregated depth distributions, and depths sampled from the depth distributions aggregated over the same day as the sampled environment in the simulation. The static depths are 50 m for the sonar and 120 m for the submarine. The difference between sampling from the 5-day distribution and the same day can be seen as a measure of uncertainty in the evaluation of the environment, where sampling from the same day distribution implies the highest degree of confidence in the unit's own environmental knowledge.

The area and times sampled are the same as in [4], and the depths distributions are therefore also the same. The 5-day aggregated distributions are shown in figure 2 and figure 3. The choices for static sonar and target depths, correspondingly 50 m and 120 m, correspond to

depths with high probability in these distributions, indicating that they are reasonable choices for static depths in this study.

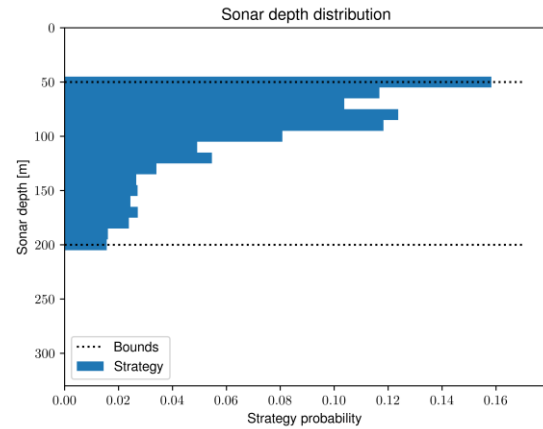


Fig. 2. Distribution of optimised sonar depths for a variable environment over 5 days, using the method described in [4]. The available sonar depths are bounded between 50 m and 200 m.

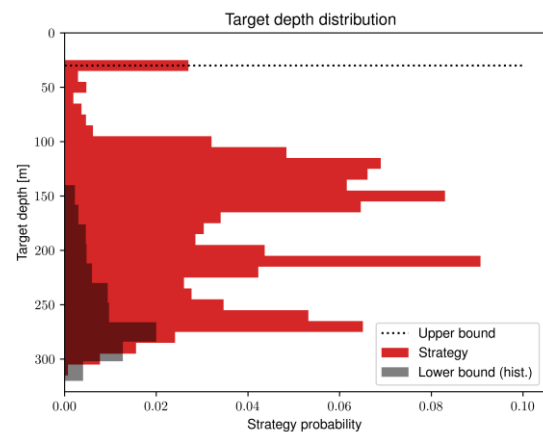


Fig. 3. Distribution of optimised target depths for a variable environment over 5 days, using the method described in [4]. The available target depths are bounded between 30 m below the surface and 30 m above the current bottom depth. The latter varies throughout the sampled area and is therefore shown as a histogram.

4 Results

The scenario is simulated over 180 000 times, so that the 9 distinct pairs of opposing strategies are evaluated more than 20 000 times each. The results are shown in table 1, where the proportions of runs ending with an initiated track on the submarine are used to compare the strategies. Compared to the benchmark 60% where both agents use static depths, when an agent uses a depth sampled from a distribution of Nash equilibrium strategies, they both win in about 10% more of the simulations if the other agent is still using a static strategy. The difference between sampling from distributions from all 5 days versus the same day is less pronounced, but in almost all cases its more advantageous to use a distribution aggregated for the same day. The min-max “hyper-strategy” equilibrium is

for both agents to use the same day distribution strategy, as neither can improve by alone selecting a different strategy.

Table 1. The proportion of simulation runs ending with a track initiated due to detections in 3 out of 4 consecutive pings. Total number of runs is 184 464.

Track initiation proportion	Target depth = 120 m	5-day target depth dist.	Same day target depth dist.
Sonar depth = 50 m	60%	52%	51%
5-day sonar depth dist.	70%	63%	61%
Same day sonar depth dist.	69%	64%	62%

Another result is that courses selected closer to the ASW platform are more likely to be detected, which is as expected. Additionally, the rate at which the agents “resample” their depth distributions and select another depth during the runs did not affect the probability of track initiation.

5 Conclusion

The results show that the agents which use intelligent game theoretical strategies have superior performance compared to the agents which only use a reasonable single depth. If one of the agents has a more accurate picture of the sonar environment, it will gain an edge over an agent whose knowledge of the environment is more uncertain.

Both the generation of the recommended depth distributions and the simulations use realistic ocean model data, depth profiles and acoustic propagation models. The higher the degree of environmental fidelity the simulations use, the more certain we can get that the methods for sonar parameter optimization are viable in real operations. In this way, the methods developed for simulations can be used for real world cyber-physical systems, like autonomous ASW platforms. As the success depends on the accuracy of the environmental knowledge, this challenges us to make sure that autonomous ASW platforms can measure and share their knowledge with their peers. This *social ability*, to cooperate and coordinate their sonar usage, is a logical next step for scaling up the complexity of ASW simulations.

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Speaker Biography

Kristoffer Engedal Andreassen is a scientist working for the Norwegian Defence Research Establishment (FFI), engaged in simulations and analysis of sonars in ASW. Andreassen has an M.Sc. in Applied Physics from the Norwegian University of Science and Technology (NTNU).