MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

**Research Note**

# Passive Sonar Simulator: Vulnerability Assessment


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## 1. INTRODUCTION

The rise in awareness and interest of marine resources and resulting tensions has created the need for security and assessment of deploying a ship in a region. Vulnerability assessment is the study of how vulnerable one's ship is to detection by others. It is done by using the sonar equation and calculating the reverse signal to noise ratio in the surroundings. The survivability of the naval ship is the capability of a warship to avoid or withstand a hostile environment. The survivability of the naval ship assessed by three categories (susceptibility, vulnerability and recoverability). The magnitude of susceptibility of a warship encountering with threat is dependent upon the attributes of detection equipment and weapon system.[1]

Maritime threat detection is a challenging problem because maritime environments can involve a complex combination of concurrent vessel activities, and only a small fraction of these may be irregular, suspicious, or threatening. This is important in the context of Indian Ocean, which is an important trade and strategic route.

Previous work on this task has been limited to analyses of single vessels using simple rule-based models that alert watch standers when a proximity threshold is breached. This work aims to look at existing technologies and use them to model a 3-D threat assessment map. It also aims to briefly study different statistical models to calculate vulnerability.

## 2. DOMAINS INVOLVED

● Indian Ocean Region –

The complexity of the tropical waters of the Indian Ocean make operation of sonars difficult as it degrades it's performance. Different models are needed to calculate the parameters of passive sonar equation due to these complexities. The high SOFAR depth means that sonars are not able to maximise the use of underground sound channel. The Parabolic Equation is the most suitable equation to model Transmission Loss in IOR. [2] ● Probability Graph Models –

Naval ship's survivability emphasizing the susceptibility is assessed by the probability of detection, and the probability of hit. PGMs offer a number of benefits for modelling relations in a complex domain. They provide a compact encoding of a distribution in a multi-dimensional space, model variable independencies, and have well understood mathematical foundations. When selecting which PGMs to use in a given domain, trade-offs must be made between feature expressiveness, learning, and inference costs. Some of these models include: 1. Hidden Markov Models (HMMs)- An HMM is a generative model of a probabilistic sequence. An HMM model is a graph whose nodes denote hidden states and whose links denote transition probabilities from one state to another . the Viterbi algorithms, respectively. HMMs have been used successfully in many tasks such as natural language processing, speech recognition, and modelling of dynamic agents. Although they model temporal relations, they cannot compactly represent local features and spatial relations.[3]

2. Conditional Random Fields (CRFs) A linear chain CRF is the discriminative counterpart to the generative HMM and can also be used to model a sequence or an agent's actions in a temporal domain. Unlike HMMs, a CRF can model local and temporal features. However, CRFs are limited in their ability to naturally model expert domain knowledge. For example, they cannot model relational spatial features such as the distances between multiple pairs of ships in a maritime domain. [4]
3. Markov Logic Networks (MLNs) MLNs combine first-order logic (FOL) with a probabilistic interpretation to represent expert domain knowledge. MLNs are a more general model than CRFs or HMMs, and this allows them to be applied to many of the same tasks. Also, an MLN can encode a greater amount of relational knowledge, which makes them useful in scene understanding, object recognition, and activity recognition. In the maritime domain, MLNs can more easily encode relational spatial features, which allow them to model vessel behaviours more accurately.[5]

- Ambient Noise Mapping -
  The low-frequency band is dominated by anthropogenic sources: primarily, commercial shipping and, secondarily, seismic exploration. Shipping and seismic sources contribute to ambient noise across ocean basins, since low-frequency sound experiences little attenuation, allowing for long-range propagation. Over the past few decades the shipping contribution to ambient noise has increased by as much as 12 dB, coincident with a significant increase in the number and size of vessels comprising the world's commercial shipping fleet.[6] Since sonars mostly operate in this frequency range, it is important for accurate and real time mapping of the region. Higher noise level also reduces the probability of detection by other vessels.
- Radiated Ship Noise -
  Noise generated by ships is of keen importance for military as well as non-military organisations. It has an impact on the environment, well-being of workers on board and the probability of being detected. Thus, great care is taken while designing ships to minimize the ship radiated noise as much as possible[7]. Submarines produce cavitation bubbles when they move underwater. This noise can be picked up by sonars to detect the submarine. Submarines try to move at speeds which minimizes formation of cavitation bubbles. Major research in propeller designs is underway and propeller designs are classified to prevent enemies from copying the design.[8]

## 3. CHALLENGES

- Compatibility across platforms –
  The system should be flexible to be implemented on different platforms, according to various hardware and software specifications. This is a challenge in the secretive military domain. Hence, militaries are increasingly moving to open architecture to fast track their innovation.[9]
- Real – time assessment is computationally heavy –
  Signal processing algorithms and simulation software are computationally heavy. Complex and expensive hardware is required for efficient functioning of the software.
- Estimation of receiver characteristics –
  The array gain term plays an important role in the passive sonar equation. While calculating the reverse signal to noise ratio, we have no way of estimating the receiver characteristics and array gain.
- Indian Ocean Region –
  Sonar performance is significantly degraded in the Indian Ocean region. This makes many models ineffective and also affects detection range. Also, there is limited research done in the Indian Ocean Region. The majority of the work has been done in colder seas and this data is not suited for the tropical littoral waters.
- Infrared Homing –
  Advances in technology have resulted in development of weapons such as long range weapons and infrared homing missiles. The infrared homing missiles are passive devices which use the infrared (IR) light emission from a target to track and follow it. This makes them extremely difficult to detect.[10]

## 4. APPLICATIONS

It is used in combat management systems[11] to perform various tasks such as:

- Monitoring and awareness of surroundings –

Information of surroundings is collected through sensors like radars, electro-optical systems and sonar. This environmental information is then converted into actionable data by interpolation and evaluation for interpretation by human operators.

- Weapon Control Systems –
  Incoming threats such as missiles and torpedoes are tracked. The system is also capable of destroying threats through an automated process.[12]
- Identifying targets –
  The CMS is also able to distinguish between enemies and allies which is a key aspect of vulnerability assessment.

## 5. WAY AHEAD

- 3-D Depiction of Vulnerability Map for efficient depiction of data –
  There has been rise in data inputs due to evolving technology. The existing 2-D models are unable to depict the data effectively. 3-D modelling and mapping software could be used to implement the data and capture the real world.
- Automating data analysis to avoid human error of judgment –
  There is a continuing trend of letting fewer people deal with larger amounts of information in more complex situations using highly automated systems. In such circumstances, there is a risk that people are overwhelmed by information during intense periods or, on the other hand, do not build sufficient situational awareness . Current literature shows no examples of adaptive automation in real operational settings. Automated machines could be built to operate like a virtual team member in that it continuously builds its own view of the situation independent from the human. Working agreements between human and machine provide lower and upper bounds of automation.[13]
- Cognitive model for threat assessment –
  Liebhaber et al[14] in his work reports the results of an investigation into the cognitive aspects of threat assessment. It reports on how experienced naval officers determine threat based on input data, geographical location, and whether this data matches the expected value. This model could be implemented alongside existing ones to speed up computation of vulnerability assessment.
- Efficient Probabilistic Models –
  The challenges of the Indian Ocean Region create the need for newer models which can quickly and efficiently calculate the vulnerability from available data. Machine Learning models might also be implemented to save on computing time.

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