<u>**Research Note**</u>

MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

Passive Sonar Simulator Design and Development (Effective Detection)

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Introduction

The primary function of passive sonar is to detect a target amidst the ambient noise that is present in the background and the Transmission Loss associated with underwater sound propagation. Sonar performance modeling [1] is used to quantify the sonar performance in the context of effective detection by having a careful and detailed analysis of the terms involved in the passive sonar equation [2]-[4]. The depiction of Transmission Loss curve, low frequency ambient noise mapping, solution of Receiver Operating Characteristics (ROC) curve with the help of complex mathematical models is essential for the effective usage of sonar and help us visualize and solve the real world problems. With the help of the Receiver Operating Characteristics (ROC) for varying values of (Signal to Noise Ratio) SNR, Detection Threshold (DT) and the study of existing models and techniques to find the Transmission Loss, effective range can be calculated. The detection range thus found can be used for searching or controlling any area of interest in the ocean and provide theoretical support for the efficient use of sonar equipment.

Relevant Domain

Receiver Operating Characteristics

- The signal picked by passive sonar is a linear sum of the signal due to the target with the Transmission Loss and the background noise present in the ocean. Detection range is the maximum range from the passive sonar when the probability of detection a target is 50% [1]. However in practical application of sonar, detection range for different detection probability must be considered and focused upon. The probability of detection and false alarm is the chance of detecting a target correctly or incorrectly respectively. Effective detection range changes as the probability of detection is changed.
- The Receiver Operating Characteristics (ROC) is used for the assessment of sonar detector. They often describe the relationship among the probability of detection (Pd), the probability of false alarm (Pfa) with the signal-to noise ratio (SNR) as a parameter. The Detection Threshold (DT) is the value from sonar equation for a specified

Probability of Detection (Pd).

Transmission Loss

- Underwater channel modeling gives the Transmission Loss associated with underwater sound propagation in the ocean environment . A range dependent model will give one a close approximation of the real world Transmission losses and problems associated with it. The RAM (Range Dependent Acoustic Model) [5] based on Parabolic Equation (PE) approach [6] is the most suitable in the Indian Ocean Region (IOR) and is useful in the low frequency range of 500Hz. [7]-[8].

Effective Detection

- The traditional method for evaluating the uncertainty of Sonar detection range mostly focuses on the influence of the ocean environment parameter variation on the passive Sonar detection range [9]-[11]. This mainly included the study of Sound Speed Profile (SSP) (in the water column), medium uniformity, target characteristics, sea-surface roughness and bottom properties, sound speed gradients, depths of layers, roughness etc.. However, along with this the detection range is also affected by the detection probability condition and more focus on this aspect is needed.
- Effective detection of sonar will be possible by carefully analyzing the passive sonar equation which include the Source Level, Noise Level, Array Gain, Transmission Loss etc.. The noise and signal sound pressure samples are assumed to satisfy the Gaussian distribution, the signal amplitudes are subject to the Rayleigh distribution after narrowband processing by the receiver The solution of ROC curve is used to find out the Detection Threshold for varying values of Pd and Pfa. The effective detection range is dependent on the Transmission Loss curve and the Passive sonar equation for a fixed Detection Threshold. For different values of probability of detection decided by the user, the corresponding detection range can be found out [12]. There is naturally a trade-off between the range and detection probability. If we keep high probability of successfully detecting a target (Pd) and low value of not detecting it correctly (Pfa), the detection range must be compromised. Hence with the constraint of passive sonar array gain and signal processing method, the relationship between the probability of detection and the passive sonar detection range is established by using the ROC curves, the propagation characteristic curve and the passive sonar equation. According to the user's requirement at the need of the hour, a direct relationship between the detection range for a specified probability is obtained, thereby attaining the goal of effective detection.

Shipping radiated noise and ambient noise mapping

- Modeling the effect of shipping noise serves as a significant contribution in finding the ambient noise. Among the existing models [13]-[14] used to find shipping radiated noise Wittekind model [15] separates the ship noise into 3 separate categories based on cavitation and machinery noise thus providing a proper distinction between the contributors of shipping noise. The input for this model is mainly provided by the AIS (Automatic Identification System) data. Noise map represents the underwater noise due to various sources and activities involved in the ocean, in a particular area of interest.

SNR map development

- A clear analysis of the Ambient Noise Level present and a detailed documentation of the Transmission Loss as a function of range and depth by mathematical modeling proves as a substantial effort in the direction of developing a (Signal to Noise Ratio) SNR map. This SNR map will give the Transmission Loss and the ambient noise level for varying depths of the source in a 3 Dimensional field giving the user a complete understanding and the contribution of each of the maps, and thereby contribute significantly in the decision making process of the deployment of sonar. This map will also give an idea of detecting a target in the regions where the SNR value is high, as the ambient noise level will have minimal contribution as compared to the signal of our suspected target.

The development of SNR map and the calculation of detection range for different detection probability aims to provide quantitative information for the tactical decision-making of ship commanders and delivers theoretical support for the effective use of sonar equipment.

Challenges and Opportunities

- **Relevance in Indian Ocean Region (IOR)**

  There has not been a considerable amount of study in the Indian Ocean Region. The models and the technique used above have been developed mainly in the polar ocean regions whose conditions and the input parameters involved in calculations vary significantly as compared to tropical littoral regions.

- **Accuracy and efficiency of mathematical models**

  The parameters required for the Wittekind model do not rely completely on AIS data and hence requires some knowledge on the naval architecture. The accuracy of models in the low frequency range is a concern and it can be increased by considering more ship parameters, experimental data acquisition of various ships in large numbers and considering oceanic conditions in an exhaustive and extensive manner

- **Assessments of acoustic habitat degradation**

  Many marine animals rely on sound for their survival and use it for foraging for food, navigation by echolocation and understand their environment. This takes place in low frequency range. The computation of noise maps and a careful study of the biological noise due to underwater mammals will help in finding the impact of noise on marine life.

- **Policy framework development and regulation for URN management**

  Major steps and guidelines need to be framed for IOR. Guidelines in terms of developing quieting technologies can be done to engage the shipping industry and reduce its impact on marine life.

- **Military applications**

  It is of utmost importance to find the detection range of a sonar system in any given environment for all military applications. The detection range as a function of detection probability will give the commander tactical advantage and help in the efficient use of sonar. The development of Combat management system to determine ASW (Anti-Submarine Warfare), torpedo defense can be helpful.

Research Direction

- **Development of GUI**

  A Graphical User Interface can be developed which will be user-friendly and easily understandable. The depiction of the ROC curves, Transmission Loss curves, noise mapping can be done in graphical way giving the user a complete analysis of the situation in a friendly manner.

- **3D mapping of ambient noise and Transmission Loss**

  The 3D simulation of Transmission Loss and the low frequency ambient noise mapping will help visualize the actual ocean conditions and predict the losses in close approximation to the real world. This will help us tackle the problems provided and seize the opportunities in store for us in the underwater domain.

- **Advancements in signal processing and oceanographic modeling**

  Work towards increasing sophisticated sonar performance prediction models predicting the fluctuations in the signal and background waveforms along with oceanographic features that cause them.

- **Autonomous Platforms**

  Autonomy in the working of autonomous vehicles and sonar platforms can be applied in the field of oceanic survey, marine archeology, military reconnaissance to execute a designated task.

- **Effective deployment and vulnerability assessment**

  The vulnerability assessment is done by calculating the reverse SNR using the sonar equation. Effective deployment of sonar will take place where vulnerability of sonar is low and the detection range is high. Effective detection and SNR map act as crucial input and play a significant role in deciding this.

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