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Software On Radiated Marine Noise Mapping

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Abstract —
This paper presents a survey of various methods for the mapping of radiated marine noise. The objective of this survey is to document these methods focusing on their assumptions, models, working, implementation and help the reader develop a clear understanding regarding the subject.

INTRODUCTION

A Noise map is a graphic representation of the sound level distribution of the propagation of sound waves in a given region, for a defined period. The international agreement and definitions for noise mapping were born in relation to the Environmental noise directive of the European Parliament and Council that defines a noise map as a map designed for the global assessment of noise exposure in a given area due to different noise sources. The history of underwater sound modeling takes us back to the 19th century where in 1826, a Swiss physicist Jean-Daniel Colladen and a French mathematician Charles-Francois Storm using a bell apparatus measured the speed of sound in waters of the lakes at Geneva, Switzerland using a bell apparatus leading to value of 1435 m/s at 8°C, that now comes within 2% of currently accepted values.
After sound technologies like SONARS were implemented in commercial ships and bigger vessels. It was then, with the increase in number of ships and bigger vessels over oceanic waters that drew the attention of researchers towards high levels 11 of sound radiated underwater and how it affected the marine fauna in that region. Not only that but also it affects a wide range of receivers, crew, passengers inside the ship and inhabitants of the coastal areas.

Assessment of underwater noise was increasingly required by regulators of development projects in marine and freshwater habitats, and noise pollution being a constraining factor in the consenting process. Noise levels arising from the proposed activity like of SONARS are modeled and the potential impact on species (mammals) of interest within the affected area is then evaluated. Now it's culminated that with the advancements of complexity in technology used in SONARS, it has developed our interests in knowing underwater acoustic propagation in greater detail. Although previously Ray theory and Parabolic equations were used for mathematical modeling of 2D sound propagation, its practical implementation limits its applicability in 3D analysis. Most commonly used term for this way of modeling is a (N X 2D) technique. where models were sequentially executed for N adjacent range-dependent 2D radials.

Underwater radiated noise from shipping is globally pervasive and can cause deleterious effects on marine life, ranging from behavioral responses to physiological effects. Acoustic modelling makes it possible to map this noise over large areas and long timescales, and to test mitigation scenarios such as ship speed reduction or spatial restrictions. However, such maps must be validated against measurements to ensure confidence in their predictions.

LITERATURE REVIEW

[1] Automatic Identification System (AIS) is an automatic tracking system that uses transponders on ships and is used by vessel traffic services (VTS). The information provided by the AIS equipment includes Unique Identification, Position, Course and Speed. AIS is intended, primarily, to allow ships to view marine traffic in their area and to be seen by that traffic. AIS data serves the purpose of surveillance in the ocean, keeping a record of all marine traffic in a region. However, AIS data collection is not an error free procedure, with 3 many inadequacies in the form of data lag, data repetition, and the absence of a considerable amount of marine traffic as a result of irregular frameworks and implementations of transponder requirements on marine traffic

[2] A Noise Map is a map of an area which displays the varying noise levels in a region in the form of a color-coded map, also called heatmap. In some cases, the noise levels may also be shown in the form of a contour map, which has the contour lines showing the boundaries between different noise levels in an area. Mapping the ambient noise in the ocean in the form of a noise-heatmap opens the horizon to study spatial variation of sound. A noise map of noise in water can be a source for conducting studies on various domains and is a crucial step in moving towards expanding the understanding of the Underwater Domain. The measurement of noise levels underwater can be made using a device called Hydrophone. This device needs to be placed at the location of interest and it directionally detects the sound in the region. However, this is a very tedious process of taking measurements and it is not physically possible for such measurements to be taken for the entire oceans. Instead, simulations that use shipping noise data from AIS or any form of tabulated noise emissions can effectively and accurately measure the total noise at a particular point in the oceans. This study involved simulating primarily use PE-RAM model for transmission loss calculations, and Wittekind model for noise emission values using the 4 AIS.

[3] 3D mapping means profiling of objects in three dimensions to map the objects in real-world. While there are several ways for a 3D profiling of an area or object, the method which measures the depth of an object or feature from focus is the most applicable in terms of Underwater Radiated Noise (URN) analysis. One of the best benefits of 3D mapping is that it provides the latest technical methods for visualization and gathering information. Knowledge visualization and science mapping become easier when a 3D map is available for the object/area under study. A Z value (other than x and y), gives an enhanced depth when you are collecting data for Geographical Information System (GIS) analysis. A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map, which enables us to more easily see, analyze, and understand patterns and relationships. The GIS system used in the course of this study was QGIS, an open-source software mapping software to display the relation between the 3D model and its location. 3D mapping proceeded with the help of Surfer, a contouring and modeling software.

[4] Underwater acoustics is the study of the propagation of sound in water and the interaction of the mechanical waves that constitute sound with the water, its contents and its boundaries. Underwater acoustic propagation depends on many factors. The direction of sound propagation is determined by the sound speed gradients in the water. In temperate waters, SOFAR (sound fixing and ranging) channel, guides propagation of underwater sound for thousands of kilometers without interaction with the sea surface or the seabed. Hence, the variation of noise levels on the water surface and the variation of these levels with depth form a crucial part of underwater acoustics. Such variations have the need to be mapped and studied for a better understanding of the behavior of sound underwater, especially in the Littoral waters of the Indian Ocean Region (IOR) which serves as an unfavorable zone for most acoustic communication technologies. Certain straightforward beneficiaries of such studies are SONARs, Bioacoustics and Underwater Navigation & Tracking. Underwater Noise is measured through hydrophones which are the underwater equivalent of a microphone which measures the sound in the region by factoring the pressure changes in the surrounding.

[5] Mathematical Aspects - The PE model The Parabolic equation is one such solution to the wave equation, that assumes that the propagation depends on the range as well as depth, a range dependent problem. This equation is not exactly solvable, and requires numerical techniques to arrive at an approximate solution, the state of the art being the split step Pade solution and an initial value of the solution to start with, calculated using inversion techniques with the risk of it suffering from problems stated above. Various computer programs have been written, to make use of parallel computing, in order to solve this equation [references], and the various modifications to 3D etc, referred to as the Parabolic Equation Range Dependent Acoustic Model (PE-RAM in short).

These programs require the sound speed values, bathymetry, sea state, and absorption values as inputs. The sound speed values depend on temperature and salinity [reference]. The IOR is characterized by saline hotspots and temperature fluctuations, which may lead to errors. Bathymetry data as well as absorption data is readily available for the IOR. The PE-RAM model does have a really high accuracy, provided some manual input terms are input appropriately. These include the range and depth step sizes, and the number of Pade terms to calculate for (See Split step Pade solution). The model then undergoes a complex matrix decomposition task, for each of the range steps provided, finally providing the transmission loss as a function of range. These manual parameters, if selected too low, can drastically improve accuracy, but increase computational costs as well, whereas large step sizes can lead to inaccurate transmission loss.

[6] Machine Learning aspects - Machine Learning is a very recent field, owing its advances to increase in computational power, and availability of data. These effectively learn to model the data provided, without being explicitly told to do so, in other words, converting experience into expertise or knowledge. Traditional Machine Learning techniques were limited to linear methods, with emphasis on human intuition to generate better features from the available data for better performance in prediction[reference]. Deep Learning, being an extended version of Machine Learning, takes it a step further, and is able to solve many more complex modelling tasks. Deep Learning models (also referred to as Artificial Neural networks or ANNs) also make use of non-linearities, which are able to capture the non-linear dependence on features effectively, implying less reliance on human intuition for feature engineering. These approaches are first, given an input, called "train data", which helps the model develop its features and dependencies. In real time usage, it uses its learnt model and features to predict. Non linearities used mean that the usage is limited to matrix multiplications, which is a pretty easy task for computers. One of the main advantages of this approach can be the reduced dependencies on manual inputs (step sizes, Pade terms as mentioned above). The next is that matrix multiplications can be done instantly by a computer, whereas matrix decomposition takes a lot of computation, thus reducing the computational cost in real time usage. However, training times for ANNs can be huge, but this step has to be performed only once for usage of the model in real time.

CHALLENGES AND OPPORTUNITIES

Monitoring the complexity of modelling - Even though ANNs can learn really complex data, it might end up utilizing many hidden layers to do so. Even though matrix multiplications are easy to compute, too many of them may lead to slower processing, and very deep networks may end up taking more compute than the original PE RAM model, essentially rendering the ANN useless in front of it.

Data Availability and Hardware Limitations - Data for the Indian Ocean is scarce as compared to the other oceans and seas. Since we are aiming at a model specifically for the IOR, not training on high quality data may lead to the ANN learning wrong representations of features[19], detrimental to the calculation of the loss in real time scenarios. Moreover, training ANNs requires efficient and state of the art hardware, the lack of which might limit the search for the best possible ANN.

Using PE RAM model as a benchmark - While training, the outputs from the PE RAM model is being used. This implies that the model is limited to the accuracy obtained by this model, and it might prove difficult for the ANN to perform better than this.

Reduction of data required - Since ANNs are fairly accurate at forming feature maps, the output of all the hidden layers can be analysed to see how much each feature contributes[20]. This may help us get rid of features that do not contribute anything to the final output, essentially reducing the complexity of the problem being addressed

Automation of Data collection - Using scripting languages, datasets may be parsed to collect the relevant data. This implies that real time usage entails only the input of Sender and receiver latitude and longitude, which when run through the model, produces the transmission loss of a signal between two points

Tailored for the IOR - ANNs, as stated above, are really good at learning feature dependencies. Since this particular ANN is being trained on data obtained from the ANN, this model will be fairly accurate upon being deployed for the IOR.

RESEARCH DIRECTIONS

Choosing the best ANN architecture - There exist almost infinitely many ways one can build their ANN. This implies there are architectures not explored yet, that may lead to better results. Some things that can be optimized are the number of hidden layers, the number of neurons for each of these hidden layers, the activations to be used, maybe shortcut learning [23], and so many more to explore. The key catch must not cross the time taken by the PE-RAM to calculate the transmission loss, else it defeats the purpose of the ANN replacing the PE-RAM.

Hardware and Software - Since this is a system to be run on ships, a further research topics may be to optimise the ANN to run on hardware present on ships. Moreover, even this process of prediction can be sped up using parallel computation, if such technology is present on the ship, then they may be leveraged

Neural ODEs - The approach being employed essentially gets rid of the Parabolic equation, and replaces it with a black box. Recent developments in solving ODEs using ANNs[22] shows some promise in this direction. Instead of scrapping the PE, we may employ this technique to solve the PE more accurately. There are still questions unanswered about the computational efficiency of this technique.

Training on empirical data - As mentioned above, this model is limited to the accuracy obtained by the PE RAM model. There is a possibility of extending beyond this upper bound, by letting the ANN learn directly from experimental data

Comprehensibility - An added disadvantage from using an ANN is the model becomes less comprehensible. Even though the ANNs can learn non linear feature dependencies, it isn't easy to exactly decode what these are. Several works have been published in this field [21] and this still remains an unsolved problem. Hence, the ANN may have to be treated as a black box

FUTURE SCOPE

The project, in all its innovation, restricted the study to tabulated noise data from AIS. We must note that the noise in the ocean has many contributing sources apart from ships. These sources can be natural as well as other man-made sources. A way ahead would be to include all anthropogenic noise while creating such maps to actually study the adverse effects of the maritime industry on the marine eco-system. With the daily breakthrough and advancements in technologies, efforts must be made to update the procedure for the development of such a 3D model. These innovations may range from the field of data collection, i.e., finding better implementations of the AIS systems, or the calculation phase as discussed earlier, and even the mapping phase especially with the recent advent in x64 computer architectures along with VR and other Visualization technologies. During the study to find a suitable software to create a 3D model.

We also came across a software called 'Voxler' by Golden Software. Voxler is a 3D data visualization tool that can also be used to create a better 3D model. It wasn't the focus of this project due to time constraints and the high learning curve of the software. Automation of Data collection - Using scripting languages, datasets may be parsed to collect the relevant data. This implies that real time usage entails only the input of Sender and receiver latitude and longitude, which when run through the model, produces the transmission loss of a signal between two points.

CONCLUSION

Acoustic waves are the main medium of propagation of signals under the water. This makes it immensely important to understand the propagation characteristics and model them for various applications, including but not limited to ocean mapping, military and sonar applications etc., more so in the IOR due to its strategic location with respect to military and trade aspects. The developments till now have been purely mathematical and involve solving differential equations of the acoustic field pressure numerically, providing us with the transmission loss at ifferent conditions. Different approaches have been taken, each based on different assumptions, leading to various models created, such as the ray tracing model, the normal modes model, and the Parabolic Equation model, which is the most suitable for the Indian ocean region, due to the range dependent nature of the ocean, which is solved numerically to arrive at the transmission loss. Such numerical solutions run into many errors and bottlenecks, where Machine Learning and Deep Learning techniques fare better than these. Moreover, the Indian ocean is physio graphically different from the rest of the oceans in the world, characterized by salinity hotspots, lower depths, shallow littoral waters, wild temperature fluctuations, among others. These can be tough to account for in mathematical models, where ML and DL models can perform better. We take a look at both approaches, and the research directions ahead.

Since this is a system to be run on ships, a further research topics may be to optimize the ANN to run on hardware present on ships. Moreover, even this process of prediction can be sped up using parallel computation, if such technology is present on the ship, then they may be leveraged.

- As mentioned above, this model is limited to the accuracy obtained by the PE RAM model. There is a possibility of extending beyond this upper bound, by letting the ANN learn directly from experimental data

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