Research Note-2

Review of AIS driven Shipping Radiated Noise Estimation Techniques

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The Automatic Identification System (AIS) is a tool for identifying and monitoring maritime traffic by sending and receiving vessel information to nearby ships and coastal authorities on two dedicated VHF radio frequencies. It was originally developed to be used as a collision avoidance system but later evolved to be useful in many more applications all of which has been explained in detail in our first research note [1]. One of the many applications of AIS data is estimation of Shipping Radiated Noise.

Since the start of Cold War in 1947, estimation of shipping noise levels has been an important aspect from both marine conservation as well as national security perspective, considering the dominant contribution of ship in the low frequency ambient noise levels of the ocean [2]. Donald Ross, an acoustics expert, who worked with the U.S navy largely during the cold war, studied the low frequency ambient noise data collected from the hydrophone array which were part of the SOSUS (US Navy Sound Surveillance System) over the year 1950-1970 and in his book, aptly described how sounds radiated by surface ships play a key role in naval warfare by revealing their presence to enemy submarines and limiting the ability of SONARs to detect targets [3]. Over the years, the shipping noise estimation techniques as well as the applications have evolved quite a bit with advancement in technology and now has relevance to multiple military and non-military applications across multiple stakeholders including maritime security, blue-economy, environmental regulators and disaster management authorities and the science & technology providers [4, 5, 6].

The aim of this work, is to identify all the techniques that have been developed so far, which enable us to derive shipping radiated noise based on Automatic Identification System data. Much of the research that has taken place shows the usage of AIS, either as a standalone source of information for deriving shipping noise or use the AIS data in conjunction with other recording platform such as hydrophones. The research work that has been done using both the techniques are discussed below.

Use of AIS in conjunction with Hydrophones

It has generally been asserted through ongoing research that the most pragmatic means of quantifying vessel emitted sound is to opportunistically capture noise via a stationary hydrophone (or network of hydrophones), and then make inference about the vessel noise emissions at source. AIS data have been used to "pin down" the emitter location while acoustic modelling is applied to received signals in consideration of these locations. This technique is called as Closest Point of Approach (CPA) and is currently the only technique (to the best of our literature survey as on the date of publishing) that is employed while using AIS in conjunction with Hydrophones.

The technique of CPA has been existing since the very advent of AIS but was being used by the coast guard for a different purpose of detecting suspicious vessels by verifying the AIS detected vessels against their sonar readings, but the use of CPA for ambient noise estimation was suggested by Coward in 2013 [7]. Coward in his work suggested a method for ship source level noise estimation by matching vessel CPA to sound pressure level (SPL). He collected noise data from hydrophones deployed within Norwegian waters and then distributed the noise to adjacent vessels that he identified using AIS data. The transmission loss between the recording site and vessels were accounted for using complex acoustic propagation models RAM and LYBIN for a frequency range of 10 Hz to 3 KHz.

Applications

The method of estimation of shipping radiated noise by using AIS in conjunction with hydrophones have been adopted by various researchers to tackle multiple problems. Few of the most interesting research problems that have been considered in the past decade or so has been described below.

- Identifying conditions that lead to generation of increased acoustic footprint of container ships: McKenna et al. 2013 [8] used the approach to develop and evaluate statistical models of container ship noise in relation to design characteristics, operational conditions, and oceanographic settings. The results provided an insight on the conditions that produce higher levels of underwater noise from container ships.
- Marine Conservation : The initiative of marine conservation using estimation of shipping noise derived from hydrophones has experienced many works such as that of Hatch et al. 2008 [9]; Listewnik 2014 [10] etc. over the past decade. One of the most pivotal work in this domain was done by Veirs et al. 2016 [11] who estimated underwater sound pressure levels for 1,582 unique ships that transited the core critical habitat of the endangered Southern Resident killer whales during 28 months between March, 2011, and October, 2013. This is the first study to present source spectra for populations of different ship classes operating in coastal habitats, including at higher frequencies used by killer whales for both communication and echolocation.
- Validating Impact of Slow Steaming Practice on ship radiated noise levels: Leaper et.al 2014 [12] carried out an interesting research on the effect of slow steaming practices on acoustic footprint of the ships. In his work he described how slow steaming practices since 2007, resulted in an observed reduction in mean speeds from 15.6 knots in 2007 to 13.8 knots in 2013 for ships transiting the major shipping route in the eastern Mediterranean. Based on general observed relationships between speed and noise for vessels with fixed pitch propellers, they estimated that slow steaming in the last five years has likely reduced the overall broadband acoustic footprint from these ships by over 50%.
- Supporting Framework Directives : Garrett et al. 2016 [13] used a similar approach to assess ocean ambient noise in Falmouth Bay UK, as a function of seasons, shipping activity and wave height, providing comparison points for future monitoring activities and to support the European Union's Marine Strategy Framework Directive (MSFD).'
- Predicting future shipping noise using probabilistic framework : Aulanier et.al 2017 [14] in their unique work, develop a probabilistic framework, called RAMDAM, to estimate, map and compare the shipping noise effect probabilities within four large-scale regions of the Canadian Arctic and Sub-arctic regions from AIS data obtained of the year 2013 and considering how shipping noise has doubled every year in their region, predicted a 10 fold (x10) increase in shipping traffic and thus estimated shipping noise in their region for the year 2017.

Standalone use of AIS

The above mentioned technique of using Hydrophones although provides a nearly accurate result, has multiple downsides to it. The process of hydrophone deployment along with DAQ integration in order to estimate ambient noise levels is an expensive procedure considering how the hydrophones are limited by their hardware capabilities and provides erroneous or sometimes no output when subjected to adverse environmental conditions. Moreover, analysing the data recorded by hydrophones are most of the times a static procedure thus not allowing a dynamic spatio-temporal analysis and prediction of ambient noise levels which is the need of the hour especially in India where the shipping traffic is rising at the rate of at least 2.79% every year [15] and has a direct impact on low frequency ambient noise levels in the ocean.

The book (*Mechanics of Underwater Noise*) published by Donald Ross in 1976 [16], described propeller cavitation of the ship and impact of bubbles on the cavitation as the dominant source within the ship generating noise at lower frequencies and thus proposed a formula to estimate the shipping radiated noise using Length, Speed and Draught of the ship, which can be obtained from AIS data. The proposed model opened door to new research areas as now the ambient noise levels can be dynamically estimated without the need for recording noise levels using hydrophones.

Donald Ross model although was unique, faced a lot of criticism for overestimating ship source levels at higher frequencies (above 500 Hz). Stephen et.al 2001 [17] in their work provided a new source spectra model as an advancement to the Donald Ross model and pointed out that the issue in D.Ross model was due to the wrong assumption of power-law relationship between ship speed and length. He verified his model by proving that the rms (root mean square) error obtained via his model is lot less as compared to D.Ross model at higher frequencies.

Applications

It goes without saying that shipping noise estimation by standalone use of AIS or its usage in conjunction with hydrophones is merely a technique, and irrespective of the technique adopted, the applications can be same. Hence, in this section we have mentioned some of the interesting research works that have been performed in the past decade with standalone usage of AIS.

- Marine Spatial Planning : The marine spatial planning involves studying and discovering areas that are habitable by the marine life in the region. Erbe et.al 2012 [18] in their work described stranding of whales and dolphins as a cause of serious concern and used the D.Ross mathematical model to obtain shipping noise from AIS data and further performed mapping of the estimated low frequency ambient noise levels in Vancouver region so as to perform marine spatial planning. Similar work was performed by Che Shuewei et.al 2016 [19] in China and Skarsoulis et.al 2016 [20] for Eastern Mediterranean Sea. There are many more works that have taken place in marine spatial planning but we focused on Christine Erbe since she was one of the early researchers to implement D.Ross model in their work thus validating the model for modern commercial vessels as well.
- Acoustic Capacity Building : Raul et.al 2019 [21] implemented the Radial Accumulation method of RANDI 3.1 model in order to obtain the shipping noise map of an area near Mumbai coastline in Arabian Sea. Prabhuraman et.al 2019 [22] implemented the Grid Based Localization method to obtain a high resolution noise map, also near the Mumbai coastline, both of which propose to contribute significantly to the acoustic capacity building of the nation. These efforts have been supported by the Maritime Research Centre (MRC), Pune India as part of their efforts for effective Underwater Domain Awareness (UDA) in the Indian Ocean Region (IOR).

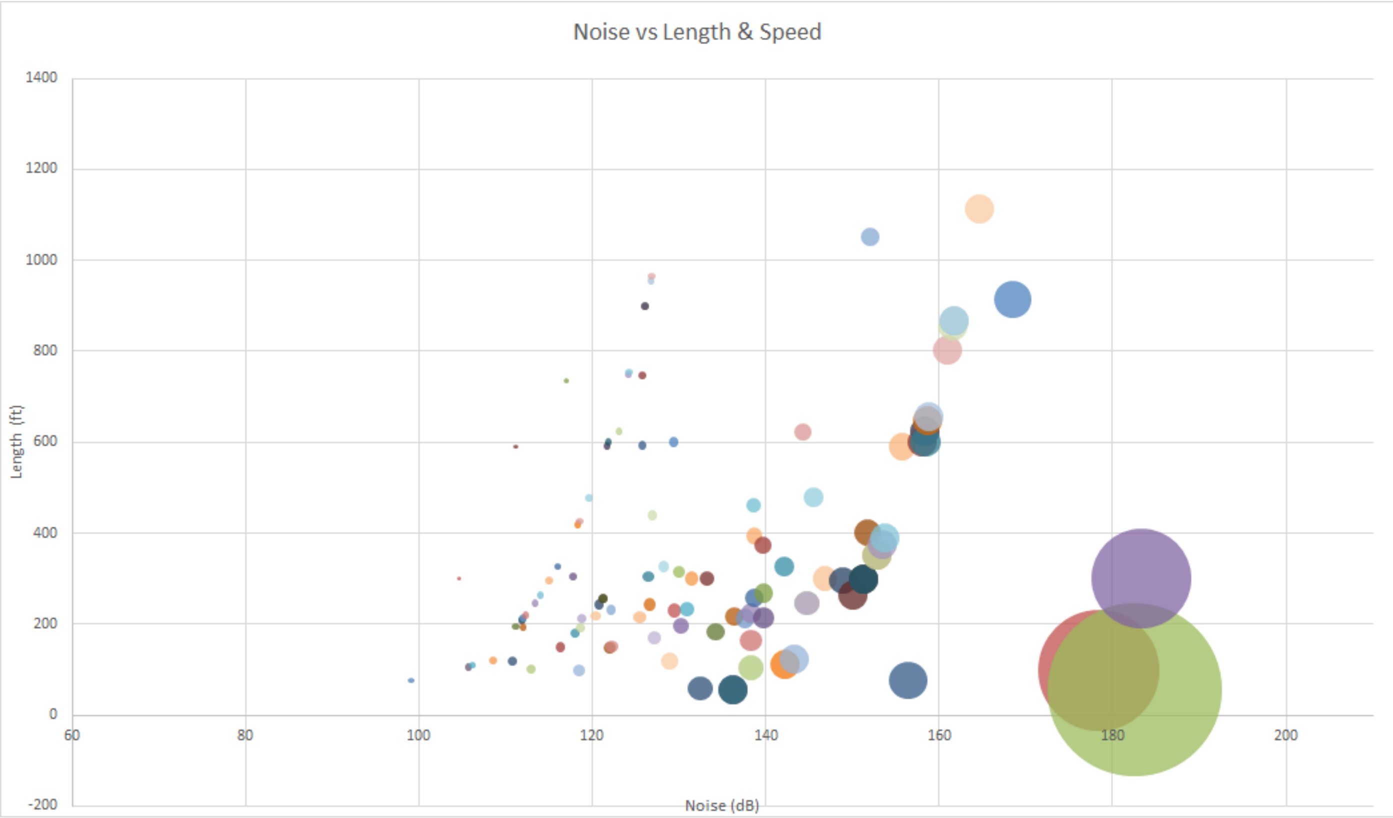
Future Scope

Even though the shipping noise estimation via the use of AIS data has found itself quite some important applications, there are still a lot of work that needs to be done, in terms of improvising the efficiency, speed and resolution of output obtained as well as further study on the applications.

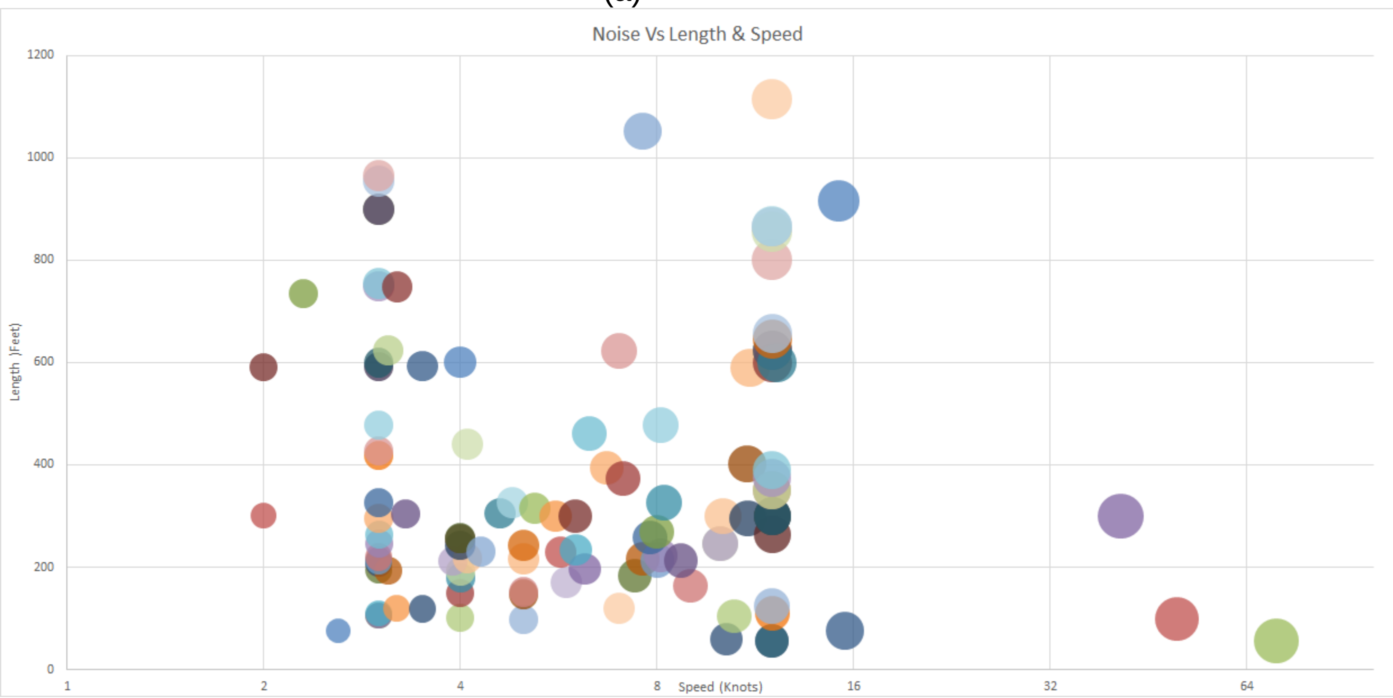
- Fuel Efficiency and Acoustic Footprint: Leaper et.al 2014 showcased how the use of slow steaming practices by vessels, reduced the vessel acoustic footprint by nearly 50%. But, the technique cannot be completely adaptable, until multiple other dimensions are looked into. One such dimension is fuel efficiency of the vessel when practicing slow steaming and its relation with the reduced acoustic foot print.
- Resolving AIS data error: The accuracy of shipping noise estimation by the usage of AIS data is limited by the ability of AIS to provide error-free output. As discussed by us in our first research note, the AIS transponder can be switched on/off by the ship's officer to tackle security challenges. Estimating shipping noise for certain applications such as marine spatial planning, supporting frameworks etc. does not really require a dynamic noise analysis, static would suffice for the same. Therefore the above mentioned problem can be solved by studying the shipping traffic and pattern for multiple years (suggestively for past 5 years since beyond that the shipping traffic as well as ship's parameters such

as speed and weight could experience changes) and then using the compiled AIS data as source of information.

Satellite AIS Data of 114 Vessels were retrieved from MarineTraffic.com all of which were of different vessel types ranging from smaller class of vessels such as Fishing Vessel, Tug etc. up to large class such as such as Tanker, Cargo etc. We implemented D.Ross model on all the 114 vessels by providing the length & speed information as input and estimated the vessel's radiated noise. The obtained Noise vs Length & Speed have been plotted in Fig 1 (a) & (b)



(a)



(b)

Fig 1. Variation in Shipping Radiated Noise for different classes of vessels, varying in length and speed.

(a) Noise vs Length, size of bubble represents speed (b) Speed vs Length, size of bubble represents noise.

The above figure tries to establish relationship between length, speed and radiated noise within the D.Ross model. In Figure 1(a), the X-axis represents Noise (dB) & Y-axis represents Length of the vessel (ft). The size of the bubble represents the speed, of the vessel. In figure 1(b), the X-axis represents Speed (Knots) and the Y-axis represents Length (ft). The size of the bubble represents the vessel's noise. Both the illustrations depict how the D.Ross model estimated radiated noise, has more dependence on the vessel speed as compared to vessel length. As it can be seen, the vessel having approx. 300 Ft length and 2 kts speed has lesser radiated noise as compared to vessel having approx. 150 Ft length and 64 kts speed. The illustration also validates the theory that steaming practices of vessels might bring down the acoustic footprint of the vessel.

- Use of ML (Machine Learning) for shipping noise estimation by standalone use of AIS data: One of the biggest disadvantage of D.Ross model is its low accuracy for modern commercial vessels as mentioned by Erbe.et.al 2015 in their work. This primarily is because the properties of vessels such as ship dimensions, speed, vessel capacity etc. has experienced a drastic change since early 90s to 21st century. Another issue with D.Ross model is it's slow execution speed when dealing with large AIS dataset. Since D.Ross is purely a mathematical model and has execution time complexity of O(n). Both of these issues contribute to the low-efficiency and less-usability of D.Ross models in modern times. In recent years, usage of ML has experienced a massive boost and supervised as well as unsupervised learning techniques in ML have brought in greater efficiency with less time complexity. Although a great deal of work has been done on vessel classification using ML techniques, very less efforts have been put in estimating the shipping noise using ML on AIS data. This could thus be an important milestone in the future.

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