Research note

Passive sonar simulator and interactive applications

Harshit Agrawal, Arnab Das

The sea lanes in the Indian Ocean are considered among the most strategically important in the world—according to the *Journal of the Indian Ocean Region*, more than 80 percent of the world's seaborne trade in oil transits through Indian Ocean choke points, with 40 percent passing through the Strait of Hormuz, 35 percent through the Strait of Malacca and 8 percent through the Bab el-Mandab Strait.[1]

The Indian Ocean region is rich in minerals, metals and other natural resources. Currently, as monitored by India, it uses conventional sonars which are not able to keep pace with the growth in complexity in the operational arenas, especially in the tropical littoral region where 80% of sonar performance is degraded. Thus for India it is of utmost concern to upgrade its conventional sonars.[2]

Sonar (SOund Navigation and Ranging) is helpful in exploring, mapping and communicating underwater domain. It uses acoustic signals of low frequency to detect the surroundings. It was originally developed to detect and track submarines. But later, it is used to map the underwater domain. Sonars are of two types – active and passive sonars. Active sonar emits acoustic signals with the help of a transducer which are bounced back by the object and received to estimate the distance of the object from the sonar. Passive sonars have only receivers which receives the signals from the environment and determine the distance. Receivers used are called hydrophones. Passive sonars have advantage over Active sonar as they detect object silently where as active sonars emit signals through which enemy ships or submarines may get to know the location of active sonar. Signals emitted by active sonars cause harm to marine animals.

Since the start of the Cold War, US invested billions of dollars in naval security and defence. It laid a large network of hydrophone arrays in the region of minimum distortions to detect the enemy ships and submarines. This network is called SOSUS (sound surveillance system) and was placed in The Atlantic Ocean region and The Pacific Ocean region. It was further facilitated with mobile assets called SURTASS (surveillance towed array sensor system). Now these systems are used to monitor the underwater environment. [3]

Presently, India has a series of sonar under the name of USHUS. USHUS is an integrated sonar system deployed by Indian Navy which is developed by DRDO. It can detect both underwater submarines and surface ships, torpedoes. Its production is done at Bharat Electronics at Bengaluru. INS Arihant (ATV-1) includes the advanced version of USHUS.[4]

Passive sonar

Passive sonar is a method of detecting acoustic signal emanating from sources in underwater environment. From a historical perspective, the main impetus for the research and development of passive sonar has been its military applications, in particular, the acoustic detection of submarines. Sound signals are received through hydrophone. A hydrophone is a microphone designed to be used underwater for recording or listening to underwater sound. Most hydrophones are based on a piezoelectric transducer that generates an electric potential when subjected to a pressure change, such as a sound wave. Some piezoelectric transducers can also serve as a sound projector, but not all have this capability, and some may be destroyed if used in such a manner. [5]

The acoustic data analysis in passive sonar is often decomposed into three stages: detection, classification, and localization. The task of the detection stage is to sense the presence of acoustic signals of interest in a background of noise. If there are many simultaneous contacts, a

classification stage is employed to identify which contacts represent sources of interest and which can be ignored. Upon identification of a source of interest, an attempt may be made to localize the source and track it as a function of time.[6]
There are several types of hydrophone array. Towed array, sonobuoy, hull mounted array, side scan array, etc. There are two methods to analyze the signal received from hydrophone viz. DEMON(Demodulation of envelope modulation of noise) and LOFAR(Low frequency analysis and recording). DEMON analysis requires narrowband frequencies and LOFAR analysis require broadband frequency. Broadband detection is often used to obtain an overview of the targets surrounding the own ship, narrowband processing enables the detection of target characteristic frequency lines. They consists sounds mainly due to propulsion systems and cavitation.[7]

Passive sonar simulator

Simulators allows to evaluate algorithm and control systems without going to the real underwater environment that reduces costs and risks of in-field experiment. They allow various operations to be performed on a single machine. Examples are as follows-

1. SonSim sonar simulator- It is developed by 5k systems. SonSim is based on a user configurable database to define all aspects of the underwater environment, including environmental curves (Weinz), reverberation(Mackenzie), transmission loss, SVP data, platform broadband and narrow band signature, cavitation threshold, target strength profile, etc. SonSim also include post processing and signal analysis.[8]
2. Generic sonar simulator - It is developed by DSIT Solutions Ltd. which is ideal for rapid and comprehensive training of ASW, submarine, and mine detection sonar operators.The simulator includes all aspects of sonar operation, with emphasis on training in:[9]
   - weak target detection in the presence of various noises and reverberations
   - torpedo detection

- audio listening
- classification

3. Proteus Passive Sonar Simulator - It is developed by Kongsberg Gruppen technologies. In this simulator the audio and target signature are computer-generated and used to stimulate the real sonar systems on a submarine or warship.The output from the PROTEUS Passive Sonar Simulator stimulates the real sonar's hydrophone output. Modified by real system-generated noise, the stimulated output makes the displayed target information and audio heard by the sonar operator, more representative of real-world target detection, identification, localisation and tracking and is thus highly effective for training.[10]

Hardware and software specification

Since the various sonar processors may execute at different rates, the individual processors must also have access to memory buffers to smooth the flow of results among units. A distributed architecture naturally provides modularity, which eases system integration and allows new processors to be added as needed. Finally, any architecture must support the programmability of algorithms and algorithm parameters. Most of the processors developed by SSD(Strategic System Department) have been designed as shore-based systems for sensor data recorded on magnetic media during operational submarine missions. In addition to submarine sensor data, the passive sonar processor can accept input from a device called a front-end stimulator (FES). FES can generate controlled, simulated signals to support processor test and calibration.[11]

The primary inputs to a simulator consists of commands for generating the various types of signals, plus assignment statements in which the user specifies the characteristics of the ocean environment, the sonar transmitter and receiver, active and passive targets, and the format of the simulated signal. These specifications and commands are expressed in a simple but flexible language with an object-oriented flavor reminiscent of Python or C++. They may be entered from the keyboard, read from text files, or passed via a pipe from a higher-level program. The language supports user-defined variables and comments to help make the scripts readable.[12]

Applications

1. **Tracking sound sources** -L.Mattos et.al (2014)[13] in their work have used passive sonar system for tracking the objects in the range of hydrophone array. The results obtained were verified with the data used for experimentation. They were encouraging which shows that system was able to track sound sources. The software developed for actual implementation of the passive sonar system performs a continuous process of data acquisition and analysis and provides a record of the temporal nuances in the received audio signals, what was shown to successfully enable target tracking and navigation by sound.
2. **Measuring ambient noise** - The progressive shift of the naval as well as commercial activities to the littoral waters has resulted in the sonar performance getting limited particularly due to higher ambient noise levels and also due to ambient noise characteristics being unique to the particular location. A.Das (2011)[14] in his work used LOFAR analysis of passive sonar to measure the data for ambient noise in shallow sea due to shipping noise and tide. The results showed large diurnal variations and are dependent on wind, climate pattern of location.The reported work presents the ambient noise variation at the west coast of India in extremely shallow waters (up to 30 m depth) attributed to the heavy shipping activity in the nearby port.
3. **Target Motion Analysis** - K.Brinkmann et.al(2010)[15] in their work introduced a multi-target tracking approach for narrowband passive sonar targets. After a review of some sonar specific features and a brief algorithm description, an application of this algorithm on the results of a simulated scenario was presented. It was shown that this algorithm has the capability to automatically track the relevant frequency lines of all targets without a

manual input by the user. This shows the use of passive sonar simulator in motion analysis of vessels.

4. **<u>Threat detection in estuarine environments</u>** - There are many limitations in the usage of active sonar as compared to passive sonar because firstly there is a high rate of false alarm,secondly enemy ships can detect the source signal emanating from active sonars and signal generated by active sonar are harmful for marine life. B.Borowski et.al (2008)[16] in their work discussed the principles of measurements and provides information on the parameters required for the development of passive acoustic diver detection methods and estimations of their efficacy.The source level of the diver was measured by comparing the diver's sound with a reference signal from a calibrated emitter placed on his path.The passive sonar equation was then applied to estimate the range of detection.

5. **<u>Obstacle avoidance</u>**- Conventional underwater vehicles often use imaging or scanning SONARs for obstacle avoidance.Smaller underwater vehicles may not be able to accommodate a scanning sonar for obstacle detection. Bouxsein et.al(2006)[17] in their work discussed about the sonar simulator which is based on modelling a set of circular piston transducers and the echoes are created based on specular reflections. This simulation can be used as a test bed to develop a low power solution. The simulation can aid in optimizing hardware and AUV parameter.

6. **<u>Passive acoustic detection of closed circuit UBA</u>** - Divers constitute a potential threat to waterside infrastructures. Active diver detection sonars are available commercially but present some shortcomings, particularly in highly reverberant environments. This has led to research on passive sonar for diver detection. L.Fillinger et.al(2012)[18] in their work described about array design and beamforming approach for the detection of rebreather underwater breathing apparatus(UBA). Passive sonar was used as compared to active because of shortcomings in high reverberant environments.The relatively large detection range observed (120m) suggests that the method should be able to detect quieter targets (such as military rebreathers) at shorter range, opening the potential application for choke point protection.

Future Scope

Although a considerable amount of work has been done on passive sonar simulators, there is still some work to be done to create efficient algorithms to process the signals. Some future scopes are discussed below.

1. **Combining Data From a Multisensor Tag and Passive Sonar to Determine the Diving Behavior of a Sperm Whale -** Sperm whales have dive cycles consisting of long dives separated by short surfacing phases for ventilation. This prolonged deep-diving behavior of sperm whales makes it difficult to study them using conventional behavioral sampling techniques, which emphasize visual observation of study animals. W.M.X. Zimmer et.al(2003)[19] in their work demonstrated that combining data from a tag, shipboard visual and passive acoustic monitoring of the tagged whale with a broader set of oceanographic data offers a real breakthrough in the difficult problem of studying the foraging behavior of sperm whales during deep dives. Further research of this sort can establish baseline behavior that will enable experimental study of behavioral disruption.
2. **Monitoring of tropical littoral region in IOR** - Presently, used passive sonar are not able to keep pace with the growth complexity in the operational arenas in the Indian Ocean Region (IOR). This simulator will not only monitor tropical littoral region but can also detect vulnerable ships and submarine which in turn will benefit The Indian Navy. This simulator will help in operational as well as training purposes.
3. **Design of passive sonar system** - H.Wesson (2017)[20] in his work has given description about design of AUV using passive sonar system. Design of passive sonar system depends on its application and its location where it is to be used, which is very expensive.Seeing that the feasibility of a passive sonar system on an AUV cannot be fully determined yet, concept testing via using real life collected data and simulations can facilitate a much deeper understanding of all the complexities of a passive sonar system on an AUV. This is especially true with respect to the design of the recommended retractable array and the feasibility of different types of applications of such a system.

References

[1].”Why the Indian Ocean Matters”,The Diplomat, Accessed on 03-06-2019 (Available Online).

[2].Das, A. (2014). Marine Eco-concern and its Impact on the Indian Maritime Strategy. *Journal of Defence Studies*, *8*(2), 109-130.

[3].Wikipedia contributors. (2019, January 13). SOSUS. In *Wikipedia, The Free Encyclopedia*. Retrieved 10:13, June 3, 2019, from https://en.wikipedia.org/w/index.php?title=SOSUS&oldid=878231894

[4].Wikipedia contributors. (2018, May 8). USHUS (sonar). In *Wikipedia, The Free Encyclopedia*. Retrieved 11:02, June 3, 2019, from https://en.wikipedia.org/w/index.php?title=USHUS_(sonar)&oldid=840204688

[5].Wikipedia contributors. (2019, May 6). Hydrophone. In *Wikipedia, The Free Encyclopedia*. Retrieved 11:12, June 3, 2019, from https://en.wikipedia.org/w/index.php?title=Hydrophone&oldid=895820254

[6].”Passive Sonar”, Springerlink,accessed on 03-06-2019(Available Online).

[7].”Types of sonar systems,Lofar and Demon Analysis”,Zetlab, Accessed on 03-06-2019(Available online).

[8].”SonSim sonar simulator” ,5Ks,Accessed on 03-06-2019(Available online).

[9].”Generic Sonar Simulator”,DSIT,Accessed on 03-06-2019(Available online).

[10].”Passive Sonar Simulator”,Kongsberg Gruppen, Accessed on 03-06-2019(Available online).

[11].South, H. M., Cronin, D. C., Gordon, S. L., & Magnani, T. P. (1998). Technologies for sonar processing. *Johns Hopkins APL technical digest*, *19*(4), 459-469.

[12].Goddard, R. P. (2008). *The sonar simulation toolset, release 4.6: Science, mathematics, and algorithms* (No. APL-UW-TR-0702). WASHINGTON UNIV SEATTLE APPLIED PHYSICS LAB.

[13].Mattos, L., & Grant, E. (2004, April). Passive sonar applications: Target tracking and navigation of an autonomous robot. In *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA'04. 2004* (Vol. 5, pp. 4265-4270). IEEE.

[14].Das, A. (2011). Shallow ambient noise variability due to distant shipping noise and tide. *Applied Acoustics*, *72*(9), 660-664.

[15].Brinkmann, K., & Hurka, J. (2010). Narrowband passive sonar tracking. *INFORMATIK 2010. Service Science–Neue Perspektiven für die Informatik. Band 2*.

[16].Borowski, B., Sutin, A., Roh, H. S., & Bunin, B. (2008, April). Passive acoustic threat detection in estuarine environments. In *Optics and Photonics in Global Homeland Security IV* (Vol. 6945, p. 694513). International Society for Optics and Photonics.

[17].Bouxsein, P., An, E., Schock, S., & Beaujean, P. P. (2007, May). A SONAR simulation used to develop an obstacle avoidance system. In *OCEANS 2006-Asia Pacific* (pp. 1-7). IEEE.

[18].Fillinger, L., Hunter, A. J., Zampolli, M., & Clarijs, M. C. (2012). Passive acoustic detection of closed-circuit underwater breathing apparatus in an operational port environment. *The Journal of the Acoustical Society of America*, *132*(4), EL310-EL316.

[19].Zimmer, W. M., Johnson, M. P., D'Amico, A., & Tyack, P. L. (2003). Combining data from a multisensor tag and passive sonar to determine the diving behavior of a sperm whale (Physeter macrocephalus). *IEEE Journal of Oceanic Engineering*, *28*(1), 13-28.

[20].Wesson, H. (2017). *An investigation of passive sonar on an AUV* (Doctoral dissertation, Stellenbosch: Stellenbosch University).