Interference of Biological Noise in Sonar Detection

Teresa Guarda[1,2,3], José Avelino Vitor[4], Óscar Barrionuevo[5], Johnny Chavarria[2], Maria Fernanda Augusto[2], José Garcés[5], Luis Morales[5]

[1] Universidad de las Fuerzas Armadas-ESPE, Sangolqui, Quito, Ecuador
[2] Universidad Estatal Península de Santa Elena – UPSE, La Libertad, Ecuador
[3] Algoritmi Centre, Minho University, Guimarães, Portugal
[4] Instituto Politécnico da Maia, Maia, Portugal
[5] Armada del Ecuador, Guayquil, Ecuador
tguarda@gmail.com, javemor@iiporto.com, oscarbarrionuevovaca@gmail.com, johnny_chavarria@consultant.com, mfg.augusto@gmail.com,jgarces£armada.mil.ec, lemm47@gmail.com

Abstract. There are a wide range of ambient noise sources within the underwater acoustics. Acoustic noise can vary over time in intensity and spectral composition, depending on environmental conditions. In passive sonar detection the target of interest is surrounded by several noises, environmental and other radiated noise from other sources. The acoustic detection systems in underwater warfare are important for ships and submarines that have acoustic sensors to determine the presence of any contact. The lack of information on the noise that disrupts the acoustic detection sensors and interferes with the recognition, possibly mask the contacts endangering the surface and submarine operations. In order to solve this problem, it is fundamental to develop an information system model that allow the identification of the signals of interest and classify the targets.

Keywords: Sonar, Noise, Noise Mapping, Information System, Data Mining.

1 Introduction

Sound Navigation and Ranging (Sonar), being an element of great importance can be affected by the environmental noise which is understood by the biological, seismic, hydrodynamic and maritime traffic. Biological noise is produced by marine life, which can reduce considerably the passive an active sonar detection range at sea, and as a result the response time to an unforeseen event is considerably diminished, hampering the correct time of response in underwater warfare [1].

Sound Navigation and Ranging (Sonar), being an element of great importance can be affected by the environmental noise which is understood by the biological, seismic, hydrodynamic and maritime traffic. Biological noise is produced by marine life, which can reduce considerably the passive an active sonar detection range at sea, and as a result the response time to an unforeseen event is considerably diminished, hampering the correct time of response in underwater warfare [1].

In the marine environment the main sources of biological noise are whales, dolphins, fish and other marine species, which increase the ambient noise level and this in itself affects the sonar detection range of contacts of interest and masking these contacts, worsening by the lack of information on the location, type, and frequency of sound of said species, compromising the success of the operations. Environment noise can be harmful to the sonar system, impairing the detection of the signals of interest [2].

The non-existence of information on studies, analysis, classification by types and noise areas originated by marine species of jurisdictional aquatic spaces; could be preventing the correct application of sonar functions generating a masking of contacts, making acoustic detection difficult and the development of underwater warfare proceedings.

In submarine warfare, passive acoustics detection is very important for warfare and safety procedures. In this sense, it is fundamental to create an information system that processes the frequencies of marine animals, allowing the correct application of the sonar filters, without masking the contacts. It is fundamental to create an information system that processes the frequencies of marine animals, fishes and other biological sources of noise in order to allow the sonar operators to apply the right sonar filters and use the most adequate function in the equipment, without masking the contacts. And in other hand, to stablish the most silence service mode of the engineering submarine systems to avoid self-interferences that reduce the sonar performance in biological saturated noise areas.

In the underwater warfare, acoustics is very important for warfare and safety procedures, then, the sonar performance and sonar detection range have a relevant importance, to extend the detection range and reduce the counter detection range in the operation area, optimize the sonar detection range trough adequate procedures will be decisive for officers and commander to make right decisions. The focus of this research will be on the biological noise that is produced by marine life specifically in cetaceans and fishes that affect the sonar performance and mask contacts at sea. The order Cetacea id divided in two suborders: Odontoceti y Mysticeti (Table 1) [3].

Table 1. Cetacea Suborder.

Suborder	**Common Name**
Odontoceti	Common Dolphin
	Porpoise
	Sperm Whale
	Killer whale
Mysticeti	Blue Whale
	Fin Whale
	Bowhead Whale
	Humpback Whale

This underwater bioacoustics research work analyzes the biological noise and its effect on the sonar ranges, with the purpose of developing an information system model that allows assists real-time decision-making selection process of the best sound signs identifying and classifying the targets. This process will be leveraged by Data Mining (DM) process and Machine Learning (ML) algorithms to automate species identification.

2 Background

2.1 Sound Navigation and Ranging

Sonar is an instrument that nowadays has a lot of use in navigation, in fishing, in the study and research of the oceans, and in atmospheric studies; although in its origins it was only used to locate in submarines during the Second World War [2].

Sonar encompasses different devices, with different objectives and modes of operation. In general, Sonar can be considered as a system or device that uses sound to explore and / or obtain information from an underwater environment [3].

Sonar is currently used for the location and qualification of fish shoals, marine substrate mapping, study of marine sediment composition, the location of submerged objects and various other fields of application.

Comparing with civilian sonars, military sonars (MS) operated at higher power levels, being used for target detection, location and classification. Low frequency MS are used for surveillance, gathering information in large areas.

The acoustic frequencies used in Sonar systems vary from the infra-sonic (very low) to the ultra-sonic (extremely high). There are two types of Sonar technologies: Passive Sonar and Active Sonar. Passive Sonar picks up sounds from sources; and Active Sonar, emits pulses and picks up echoes [3].

Passive sonars exploit these irradiated signals, allowing the detection and location of the target of interest; and also applying spectral analysis techniques, determine the number of blades in the propeller of the ship, and the characteristics of machinery, to classify the sources of sound and ships [3]. Passive sonar has a wide variety of techniques for identifying the source of a sound that has been detected. Intermittent sound sources can also be detected by passive sonar. Passive sonar has the characteristic of not emitting any type of signal. To detect and locate targets of interest, passive sonar is based on the detection of acoustic noise emitted by the object of interest itself [2], [3]. Being the passive sonar for military applications usually used in submarines, because the fact of not emitting a signal, ends up making difficult its detection by others.

Passive sonar systems may have a large sound database, but the sonar operator is usually the one who does the final classification.

The active sonar uses a sound transmitter and a receiver. When the two are in the same place it is called a monostatic operation. When transmitter and receiver are separated, the operation is bistatic. When more than one transmitter or receiver is used, spatially separated, the operation is called multistatic. Most Sonar operates multistage, with the same array being often used for transmission and reception [2].

The active sonar creates a sound pulse (ping) and then hears the echoes of the ping. This sound pulse is usually created electronically through a sonar projector consisting of a signal generator, power amplifier and electro-acoustic transducer. A beam former is used to focus acoustic power on a beam, which can sweep the required research angles. The sonar pulse is emitted when encountering an obstacle, and returns to the emitter; being half the time in which the "ping" took to go and return, being possible to calculate the distance of the object echoed with relative precision. The sound pulse can be a constant frequency or a chirp of frequency change. Simple sonars generally use constant frequency with a filter large enough to cover possible Doppler changes due to target motion, while more complex sonars generally use the last technique [4].

Active sonar is most commonly used in civil applications for tasks such as: autonomous navigation, submarine communication and seabed mapping.

2.2 Acoustic Underwater Noise

Noise in the marine environment is important because it masks the information contained in underwater acoustic signals. The whole signal process that the sonar must perform is to extract the information from the signal-to-noise combination. The parameter of interest here will be the signal-noise ratio [6].

In the underwater acoustic environment, noise sources are classified into two categories: radiated noise and ambient noise [2]. The radiated noise comes from artificial sources (oil extraction platforms, ships, submarines, among others). In a ship or submarine, the noise comes from its equipment contained in it; which start vibrating at certain frequencies, and the vibrations propagate through the structure of the ship or submarine and from there to the sea [3].

Ambient noise comes from natural sources presented in the ocean. Among the main sources of acoustic ambient noise, we can highlight: state of the sea; marine fauna and rain [4]. Ocean ambient noise sources and characteristics can be divided in three frequency bands: low; medium and high. And each band has a different set of noise sources, and different forms of noise propagation from the source [8]. Low-frequency sources (10 to 500 Hz), have significant potential for long-range propagation because they have little attenuation. On the contrary the medium frequencies (500 Hz to 25 kHz) have a limited potential of propagation, due to their greater attenuation and, therefore, only local or regional sources contribute to the field of ambient noise. In the case of high frequencies (> 25 kHz), acoustic attenuation becomes extreme so that all sources of noise are confined to an area a few kilometers from the receiver [8], [11].

Biological noise is generated from natural sources; marine animals, including fish, invertebrates and mammals that use sound, with specific frequency, to communicate [4]. The frequency spectrum of sound produced by marine animals ranges from 10 Hz to 200 kHz [4] (Table 2).

Table 2. Cetacea characteristic sounds frequency range.

Suborder	***Common Name***	***Sound type***	***Frequency range***
Odontoceti	Common Dolphin	Whistle	0.2 - 150
		Click	0.2 - 151
	Porpoise	Pulse	100 - 169
	Sperm Whale	Coda	16 - 30
	Killer whale	Scream	0.25 - 35
Mysticeti	Blue wahle	Moan	0.2 - 0.02
	Fin whale	Call	0.16 - 0.75
	Bowhead whale	Call	0.1 - 0.58
	Humpback whale	Song	0.05 - 10

Adapted from [4]

The biological activity affects the underwater acoustics detection ranges as part of ambient noise level, decreasing the value of the Figure of Merit (FOM) of a sonar system and masking some important tonal signals from the contacts: warships, maritime traffic, trawlers and another kind of boats, that are used by the sonar technician to classify and get important data for tracking, especially when passive tracking is used. All this information configures the tactical panorama that is used for making decision process of duty officers and commanders.

3 Biologic Noise Mapping

Currently new technologies have allowed the construction of more silent ships and submarines, that is including merchant ships, the warships to avoid detection, reducing the source level and increasing detection ranges; the merchant or commercial ships to reduce the cost of fuel using propulsion systems that have a low source levels using anti-cavitating propellers making it difficult to detect and classify.

In a subaquatic complex environment with an important ambient noise level that affect the Figure of Merit (FOM) and the detection sonar range, it will be useful to have a decision support tool like a biological noise mapping. At this point, integrating sonar and non-sonar data from multiple sources across multiple platforms is shown as an option to establish a more accurate underwater scenario, improving the process of target detection and classification and, consequently, support tactical decision-making.

The proposed information system model, the aCousticR it's organized in four combined processes: (1) Data acquisition; (2) Knowledge Discovery; (3) Data analysis and (4) Distribution (see Fig. 1).

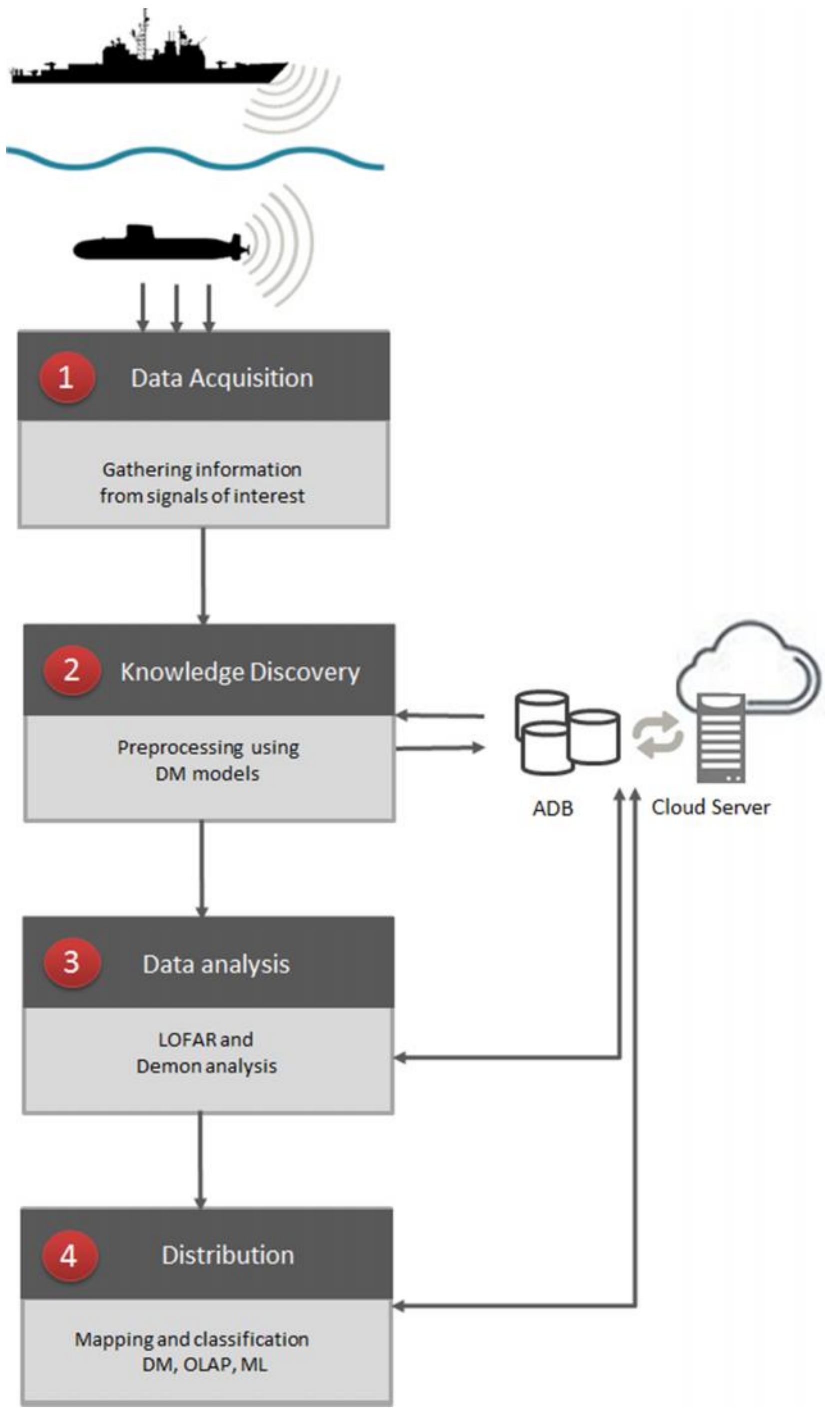

Fig. 1. Information System aCousticR Model.

aCousticR information system has two functional modes: online and offline. In the online mode the system is synchronized in real time with the cloud server; in turn the offline system remains functional, and can be synchronized whenever there is Internet access (for example, in the ports).

Despite the use of Data Mining (DM) techniques, OLAP tools and Machine Learning (ML) algorithm's that help in the automatic classification of the signs of interest; the records can be analyzed and if necessary changed by the users, in order to guarantee the quality and accuracy of the information.

The data acquisition (1) process will be made by warships and submarines that will use the sonar systems to log the reference position, time, date, estimated deep, frequency, amplitude of the signal, including sound record.

Before the data captured in the external sources are loaded into aCousticR information system MySQL databases, these data are preprocessed by DM models for Knowledge Discovery (2) that will extract, transform and load a set of heterogeneous data, which are consolidated and cleaned. DM refers to non-trivial extraction of the identification of valid, new, potentially useful and understandable data patterns from database data [9]. The DM aims to construct data models, with reference to the following models: predictive models; descriptive; dependencies and deviations [10]. The selection of DM activities is directly related to the objectives of the collection of classified biological noises (Table 3).

Table 3. DM Models.

Model	Type	Description
Predictive	Are constructed from the input data set (independent variables) for the output values (dependent variables)	
	Classification	Learning function that allows to associate to each data object one of the classes of finite set of predefined classes.
	Regression	learning function that maps each object to a continuous value
Descriptive	Discover groups or data categories of objects that share similarities and help in describing datasets.	
Dependency	Describe the dependencies or associations between certain objects.	
Deviation	Describe the dependencies or associations between certain models that try to detect the most significant deviations, considered as a reference the past behavior.	

The data obtained in this step will be load in an Acoustic Database (ADB). All the information loaded in the aCousticR databases must be analyzed (3) on the time, amplitude and frequency domains to be validated like useful. This step considers make spectrum analysis of sounds and noises recorded by the acoustics devices, using Spectrum Lab, a useful open source software. All the additional information gets in this step and useful to mapping the biological noise at sea will be uploaded in the system. The spectral analysis requires sonar technician prepared in Low Frequency Analysis (LOFAR) and Demodulation analysis (Demon analysis) of the sound that will be qualified by the Acoustical Analysis Center.

Finally in distribution process (4), the data will be mapped, geo-reference and share with the users using ArcMap. ArcMap is a geospatial processing program used primarily to view, edit, create, and analyze geospatial data; allowing user to explore data within a data set and create maps [8]. Using ArcMap, all the biological noise radiated and important data about the frequencies, noise level, type of fishes, will be georeferenced; it will permit to have graphical information. Users can explore and analyze large volumes of aCousticR data using OLAP tools, DM techniques and ML algorithms. OLAP tools are a combination of analytical processing procedures and graphical user interface, providing fast and flexible access to data and information and a multidimensional view of data. The DM aims to build data models. There are several algorithms available, each with specific characteristics. ML is part of an emerging Artificial Intelligence (AI) technology that over the last has been used by a growing number of disciplines to automate complex decision making. ML is a set of methods that allow machines to acquire knowledge to solve problems based on the history of past cases. At this level all activities must be developed to analyze data, search for patterns, and load information organized and encoded, and then the results will be distributed to end users for further feedback if necessary.

To share the information, users in the submarines or ships will have access to the system through intranet or Internet, to update all the shared information about biological noise and to the digital format of an atlas of biological noise in the ocean in jurisdictional waters.

Users had available an interface trough a cloud server or in standalone version, to the visualization and edition of data. In the case of ships that do not have intranet or Internet service at sea they will use a standalone version, and all the data will be uploading at the cloud server at port.

4 Conclusions

Biological noise information makes possible to make decision to configure sonar filters and functions, to optimize the submarine or ship machinery to decrease own noise level to increase the sonar detection range in complex underwater environmental. To optimize the sonar performance will make possible to classify contacts in an environmental with interferences of mammals, fishes and another kind of biological life that mask some tonal in the ships acoustic signature.

The biological noise mapping will allow to have information about areas where some species of fishes, mammals and crustaceans saturate the acoustic spectrum in the different periods of the year, to take forecasts useful for the underwater warfare and safety for ships and submarines. The use of the aCousticR information system allows the identification, classification and mapping of the signals of interest; in this particular case the cetaceans. The system databases are hosted in a cloud server, allowing data synchronization with all systems which integrate the aCousticR extranet (submarines, ships, investigation centers, and others).

aCousticR systems in underwater warfare it's extremely important for ships and submarines that have acoustic sensors to determine the presence of any contact. The lack of information on the noise that disrupts the acoustic detection sensors and interferes with the recognition, possibly mask the contacts endangering the surface and submarine operations.

With the use of mapping tool it will be possible to get the databases in order to define trawlers operation areas, to avoid these areas by the submarines or take actions to avoid collisions or problems with the trawlers nets.

References

1. Hodges, R.: Underwater Acoustics Analysis, Design and Performance of SONAR. John Wiley and Sons, Ltd, UK (2010)
2. Board, O., Council, N.: Ocean noise and marine mammals. National Academies Press. (2013)
3. Urick, R.: Principles of underwater sound 2nd edn. (1975)
4. Wang, L., Wang, Q.: The influence of marine biological noise on sonar detection. Ocean Acoustics (COA), 1-4 (2016)
5. Stergiopoulos, S.: Advanced signal processing handbook: theory and implementation for radar, sonar, and medical imaging real time systems. CRC press (2000)
6. Richards, C.: Sistemas electrónicos de datos: aspectos prácticos. Sistemas electrónicos de datos: aspectos prácticos. Reverté. (1980)
7. Bradley, D., Stern, R.: Underwater sound and the marine mammal acoustic environment: A guide to fundamental principles. [S.l.]., Marine Mammal Commission (2008)
8. Etter, P.: Underwater acoustic modeling and simulation. CRC Press (2013)
9. Hildebrand, J.: Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series 395, 5-20 (2009)
10. Board, O., Council, N.: Ocean noise and marine mammals., National Academies Press. (2003)
11. Ketten, D.: The cetacean ear: form, frequency, and evolution. Marine mammal sensory systems Marine mammal sensory systems, 53-75 (1992)
12. Fayyad, U., Smyth, P., Uthurusamy, R.: Advances in Knowledge Discovery & Data Mining. The AAAI Press/The MIT Press, Cambridge (1996)

13. Povel, O., C., G.-C.: Characterizing Data Mining Software. Intelligent Data Analysis 5, 1-12 (2001)
14. Minami, M.: Using ArcMap. ESRI (2002)
15. Pierce, A.: Acoustics: an introduction to its physical principles and applications 678. McGraw-Hil, New York: (1981)

Jefferson, T., Webber, M., Pitman, R.: Marine mammals of the world: a comprehensive guide to their identification. Academic Press (2011).