Automated Detection of Fishing Vessels using Smart Hydrophones on an Underwater Coastal Glider

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Abstract – AUVs operating in coastal waters where fishing vessels are also operating are at risk of becoming entangled in nets, long lines, or other fishing equipment in the water close to the surface. Autonomous gliders operating in these coastal waters are probably more susceptible to the dangers of these fishing vessels than powered AUVs, but the risks exist in both cases.

A method is proposed to minimize this risk of potential interaction with fishing gear by using two or more smart hydrophones on the coastal glider which will provide the glider with the ability to perform maneuvers that prevent interaction with gear deployed from fishing vessels. In order to command a proper glider maneuver, a fishing vessel must be detected, and classified as to type.

This paper describes both aspects of this fishing vessel avoidance issue – developing the necessary detection techniques for identifying these vessels, and the necessary performance of maneuvers that the glider must take to avoid any interaction with the fishing vessel or its gear.

***Ocean Sonics** of Great Village, Nova Scotia, Canada has developed a Smart Hydrophone with the ability to detect the radiated-noise signatures of different types of fishing vessels, and has the memory to store known signal characteristics of these vessels. With these stored acoustic signatures and characteristics, estimates can be made of the type of fishing vessel detected as well as the approximate range of the vessel and fishing equipment deployed. **Exocetus Development LLC** of Anchorage, AK has developed a glider named the **Exocetus Coastal Glider** which can perform a complete set of maneuvers. With this fishing vessel information, the **CG** control system can decide which maneuvers would be best for avoiding interaction with the fishing vessel or its gear.*

*Fishing vessels around the world have unique characteristics, and the proposed detection algorithms used to automatically detect different types of fishing vessels will be custom-tuned for the areas where the coastal gliders will be deployed. These algorithms will be discussed as well as ongoing work to improve these algorithms using data provided by operators of the **Exocetus Coastal Glider**.*

***Key terms** – AUV, Coastal Gliders, Smart Hydrophones, Vessel Detection, Event Monitoring, Ocean Sonics, Exocetus*

I. *INTRODUCTION*

*Most underwater gliders have been designed to operate in deep ocean waters, i.e. down to 1000m, resulting in operation in waters less than 20m every 6 hours, or about 5% of the time. However, the newly developed **Exocetus Coastal Glider [CG]** is designed to operate in waters less than 200m, and its operation in waters less than 20m can be anywhere from 30% to 100% of the mission time, depending on the operational scenario. This later case is when the glider mission is limited to shallow waters less than 20m.*

In many areas of the world, fishing vessels also operate in these shallow waters, and methods need to be developed to assist gliders in avoiding these fishing vessels and their fishing apparatus being towed. Therefore, fishing vessels create two problems for gliders: one, is the glider becoming entangled by the fishing gear, and the second is the glider colliding with the vessel, when the glider comes to the surface to communicate.

Other vessels in seas that are surrounded by land masses, e.g., Sea of Japan, Baltic Sea, Mediterranean Sea, etc. also have cargo vessels, and ferries, as well as fishing vessels, so that gliders must also be able to detect and avoid these vessels during operation in shallow waters.

This paper discusses how acoustic measurements by the glider can be used to detect and classify targets on the sea surface, as well localizing these targets. The issue related to the radiated noise of surface vessels is discussed in detail as well as the techniques used for classifying these vessels. We also discuss the characteristics of fishing vessels, cargo vessels and ferries. Furthermore, we describe the types of vessels and fishing gear that are used throughout the world.

We then propose a possible solution[s] of using ***Ocean Sonics'*** *smart hydrophones installed on the* ***CG*** *to avoid fishing vessels and their gear or other surface vessels using the measured radiated noise of these vessels.*

II. *BACKGROUND*

Researchers use underwater gliders to collect in-situ data in areas of scientific interest and these measurements are related to water quality and the impact that these pollutants have on fishing stock. Scientists and fishermen have had meetings to discuss the issues of operating in the same areas and how these measurement systems [including gliders] and fishing vessels can co-exist in local, shallow waters [1].

In the USA, the latest statistics [four years ago] state that the fishing industry generated more than $185 million in sales and 2 million jobs. Estimates for the fishing industry statistics in the rest of the world are about 4 or 5 times larger than the USA [2,3]. Hence, there is a very large number of fishing vessels operating worldwide in coastal waters. Fishing activity naturally follows fish abundance in coastal waters with only a few exceptions such as tuna, which are open water fish. The density of fishing vessels compared to ferries and cargo vessels is very dependent on the location of fishing areas, i.e. near large coastal population areas, where the three types of vessels coexist. However, in areas such as the coastal regions of Alaska, the density of fishing vessels greatly exceeds that of cargo vessels and ferries.

Fig. 1 shows an overview of the fishing areas of the world as well as the classification of the various categories of fishing vessels typically operating in these waters [4].

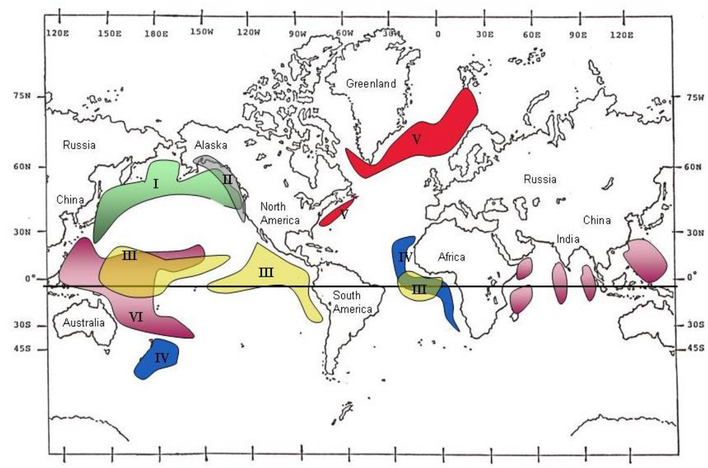

Fig. 1: Fishing areas of the world

Table 1 below defines the type of fishing activity highlighted in Fig. 1. The commercial species vary greatly and a wide variety of fishing methods are utilized to catch these species -- from simple hook and line to large and elaborate nets towed by multiple ships to weirs and traps [5].

Zone	Area	Fishing Methods
I	Bearing Sea to 200m	4 species and 4 distinct methods - mid water and bottom trawl nets, long lines and deep pots -- Pollack, Cod, Halibut, & King Crab
II	West Coast US	Trawl nets to 200m and purse seine to 30m for Hake, Herring and Salmon
III	Eastern & Western Pacific	Tuna and deep water with seine nets
IV	Chatman Rise & west coast Africa	Seine nets and deep trawls to 800-1000m for Orange Roughy
V	West Atlantic & North Sea	Mid-water and bottom trawls up to 200m for Cod, Mackerel and Herring
VI	Pacific & Indian Ocean	Pots and bottom trawls for shrimp and aquaculture

Table1: Fishing Zones of the World

III. *RADIATED NOISE OF SURFACE VESSELS IN COASTAL WATERS*

This section describes the radiated noise characteristics of ships that are operating in coastal waters and techniques for the measurement of these characteristics.

Characteristics of Ship Noise

The ability of an underwater glider to detect, classify and track a surface vessel is dependent on the radiated-noise signature of the vessel, the existing propagation conditions, the surrounding ambient noise levels [other ships such as ferries and cargo vessels or local weather conditions], and the receiving characteristics of the hydrophone system [6].

Machinery and ship propeller noise are the dominant noise sources on surface vessels when they are transiting from one port to another port. Both machinery tonals and propeller cavitation noise of vessels in coastal waters can be readily detected by hydrophones. Small ships in coastal waters typically radiate energy below 200Hz related to a ship's mechanical equipment [main propulsion or auxiliary equipment] and the dominant source above 200Hz is broadband propeller cavitation noise [7]. With the use of DEMON [Detection of Envelope Modulation on Noise] processing, not only the propeller cavitation can be easily detected, but the propeller shaft rate and blade rate can more easily be seen on the DEMON spectrum rather than on the conventional full spectrum. This leads to a very useful tool for classifying multi-targets as measured in the full spectrum [8]. Fig. 2 shows both the DEMON spectrum and the conventional spectrum for a ferry in New York Harbor with a 25-second average of the radiated-noise signature.

Diesel propulsion engines are typically found on most fishing vessels, ferries and cargo vessels, and these engines radiate energy into the water at low frequencies. These tonals are typically less than 500 Hz and are related to the rotational speed and the number of pistons on the diesel engine. Also seen in the radiated-noise spectrum are the propeller shaft rate and the propeller blade rate which is the shaft rate times the number of blades on the propeller.

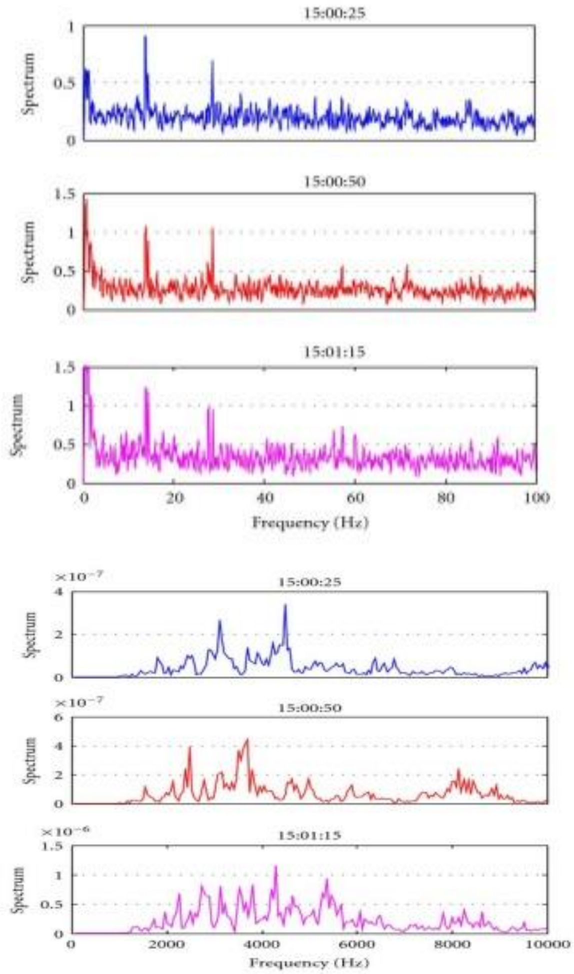

Fig. 2: Comparison of the full spectrum to the DEMON spectrum for a ferry.

Techniques for Collecting Radiated Noise Signatures

There are many ASW organizations that have very sophisticated methods and underwater systems for measuring the radiated noise of vessels [9]. These include fixed arrays of multiple hydrophones typically mounted on the bottom of an acoustic range, along with a precise tracking method for correcting the received hydrophone levels to a source level in dB re 1µPa²/Hz or a dB level in some proportional bandwidth, such as a 1/3rd octave band both referenced to 1m. As expected, the amount of time spent at these sophisticated acoustic ranges determines the accuracy of the radiated noise signature for each of several operating conditions such as varying speeds and different machinery lineups.

The number of these acoustic ranges with bottom-mounted arrays and sophisticated ranging systems are very few worldwide because of the cost to develop and maintain these ranges. Hence, the use of surface buoys or surface vessels with deployed vertical hydrophone arrays are becoming more popular. The depth of these arrays is dictated by the local environmental conditions and the vessels undergoing radiated-noise measurements.

With the recent interest in the impact of ship noise on mammals and other species in the ocean, techniques have been developed to collect these radiated noise signatures [of so-called ships of opportunity] with methods typically using hydrophone arrays located on the sea floor in, or near shipping lanes and near coastal regions [10, 11, 12]. The estimated radiated noise level of these ship signatures are based on the propagation loss models established for the particular hydrophone array locations.

The current challenge for collecting acoustic signals on a glider from nearby ships is more difficult if one wants to estimate the range to the target[s]. Determining the classification of the vessel if it is as close [less than 1000 meters] to the glider also requires some a priori knowledge. The importance of understanding the local waters where the glider is deployed is vitally important. This knowledge not only includes the physical oceanography of the region so that propagation loss estimates can be made, but also a detailed knowledge of the various ships i.e. cargo, ferry and fishing vessels that operate in the area. And it is the fishing vessels that offer the most danger to the gliders since they typically have fishing gear deployed.

IV. *A PROPOSED SOLUTION*

*This section describes our proposed solution for an underwater glider avoiding fishing vessels and other vessels in shallow water [<200m] operational areas. The **Exocetus Coastal Glider [CG]** will be outfitted with three Ocean Sonics icListen **smart hydrophones** for measuring acoustic signals on the **CG** [12, 13]. These hydrophones will be used to measure the noise levels on the **CG** and the event detection algorithms will provide estimates of the type of vessels and ranges to each of these vessels. A priori information will be stored in these hydrophones systems based on the intended operating region for the deployed **CG**. Use of three hydrophones will also allow an estimate of bearing to each of the detected targets.*

Coastal Glider Description

*The **Exocetus Coastal Glider [CG]** was developed in the mid 2000's and funding was provided by ONR [US Office of Naval Research]. The legacy gliders [three gliders originally funded by ONR]were all previously developed to collect data in the open ocean down to 1000m during extended deployment periods. ONR needed a glider designed specifically for coastal waters which could perform in waters with currents up to 2 knots and could easily operate in waters with large density variations. These large variations in density are due to fresh river water entering the coastal regions on all continents. These requirements led to a glider design with a 5-liter buoyancy engine which is about 10 times larger than the legacy gliders, and also allows the use of a patented adaptive ballasting control system.*

*Like all gliders, the **CG** operates employing a change in buoyancy to dive and ascend, and the fixed wings provide the lift to move forward in the water during these periods of motion. Additionally, the battery pack has been designed to provide the ability to steer the glider by rotating the hull about the longitudinal axis of the glider -- the **CG** of the battery pack is lower than the **CG** of the other components of the glider!*

*The **CG** communicates with the user using several different telemetry modes. However, the primary one is the Iridium satellite system when the CG is deployed and operating in an autonomous mode. The user collects the sensor data via the Internet and can also make modifications to the presubscribed **CG** mission.*

*The **CG** has a science computer for collecting data from each of the sensors installed on the glider. Typically, each sensor is sampled at 1Hz and these data are stored for analysis at the end of the specified mission. And, on an hourly basis, a 1 or 2-minute average of these data are derived and sent via Iridium to perform a validation check on each sensor. The Iridium communication mode is user-defined, but is typically transmitted every 1 to 3 hours.*

*Other communication modes available are VHF spread spectrum radio, Wi-Fi, and both cellular and ARGOS telemetry can also be specified. These various communication antennas are integrated into a single antenna housing which also includes a GPS system for providing navigation data to the **CG** navigational processor.*

The user defines a mission for the glider in the specific area that the glider will be operating, but can also define other missions which can be used to allow *the glider to return to a specific point or area based on some of the observed data. The **CG** is capable of performing multiple missions [during one deployment] one mission at a time. The **CG** mission typically contains navigating waypoints: however, the user can also define headings, speed and times to accomplish a specific track for the glider.*

*There are other operational modes the user may select such as station keeping within a given waypoint and radius or hovering at a certain depth and time. The communication mode is specified by the user and is used to determine how often he requires the **CG** to transmit the sensor data. Other modes available are the surface maneuver, which brings the **CG** to the surface for recovery, and the sleep maneuver, which turns off all power to the buoyancy system for a period of time [typically 5 minutes] to allow installed hydrophone sensors to collect data in a low noise environment. When operating in the normal glider mode, the buoyancy engine is used for the adaptive ballasting system and also for performing any trim [pitch and roll] corrections. However, these corrections use hydraulic actuators which increases the self-noise of the **CG** as seen on installed hydrophones.*

*Three additional maneuvers are designed to allow the glider the ability to avoid fishing vessels or other vessels in close proximity to the **CG**. These are the emergency rise and emergency dive maneuvers which command the glider to go to a particular depth and heading. The other maneuver used in the avoidance sequence is the surface maneuver. These three maneuvers are dictated by the **CG** control system based on the detection of one or more nearby vessels.*

Description of Smart hydrophones

Smart Hydrophones are digital calibrated hydrophones with sufficient memory and processing power to analyze acoustic data in real-time. This pre-processing of data allows the selective logging of data based on fairly complex trigger events, or allow combining processed spectral data with triggered time-series data. The firmware embedded in the Smart Hydrophone can be adapted as required for new algorithms or event types. Waveform and processed data may be logged and transmitted at the same time. Short event messages are sent when event triggers are activated or end. The hydrophones have a frequency range of 10 Hz to 200 kHz, but will be configured to operate over a narrower range, up to 6 kHz. Putting the high pass filter at 10 Hz avoids swell-induced noise, but includes the very low frequency shipping sounds.

Localization Techniques

The Hub, used for beamforming, receives data and event messages each hydrophone in real time. The data arrives time-aligned and is stored as a multi-channel digital acoustic record.

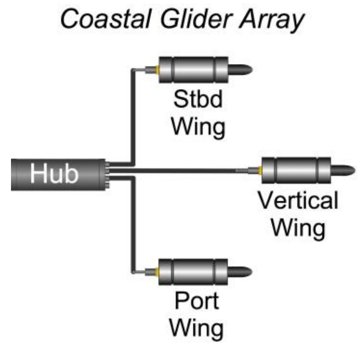

Fig. 3: Smart Hydrophone CG Array

*These smart hydrophones are located on the end of each **CG** wing and on top of the aft vertical fin. The wing smart hydrophones are about 110cm apart and the aft smart hydrophone is midway between the two wing smart hydrophones, but 26cm aft of these units and also about 55cm above them. The design frequency of this 3-element array is about 800Hz.*

With this short baseline relative to the frequencies detected, i.e. the radiated noise tonals, the localization technique uses the magnitude and phase of the event in the frequency domain. The time series is first qualified using just the magnitude, and when a valid event is detected, the phase of each hydrophone is compared to resolve the vector to the sound source for that event. Detection of multiple events is possible.

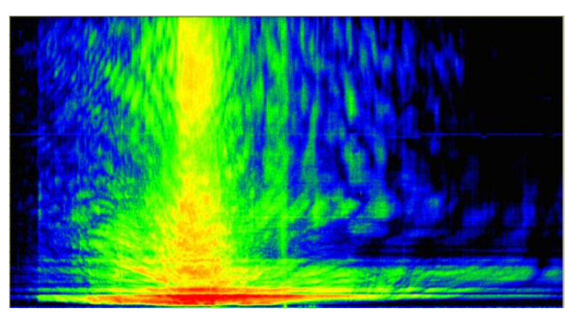

Fig. 4: Spectogram: Passing of Small Vessel

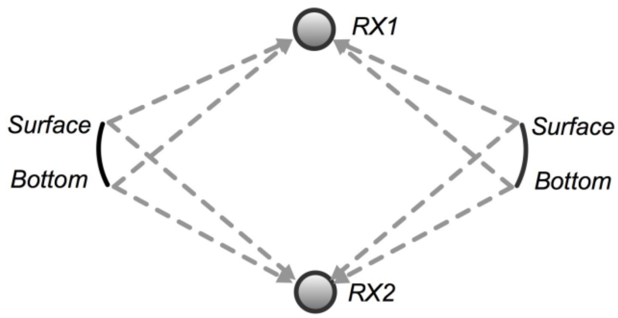

Fig. 4: Ambiguity of a 2-hydrophone array

Using a pair of hydrophones for localization gives a vector to the sound source from the baseline that joins the two hydrophones. Unfortunately, there is a mirror-image vector on the opposite side of the baseline that introduces some ambiguity in the source location. This is compounded if the sound source is not on the surface. In that case, an arc of ambiguous vectors results as seen in Fig.4, where the arc ranges from the surface to the ocean bottom.

Introducing a third hydrophone, carefully located, eliminates the mirror-image ambiguity. Since the CG is only interested in targets on the surface, mounting the hydrophone on the aft vertical fin is ideal for solving this ambiguity. With three hydrophones 4 to 6 separate sound sources may be tracked.

V. *FISHING VESSEL CHARACTERISTICS*

The importance of knowing the types of fishing vessels in the planned operational area for the ***CG*** *is vitally important! The researcher also must have a good working knowledge of all the other types of vessels, i.e. ferries and coastal shipping that the* ***CG*** *possibly could encounter. With this a priori information, the* ***CG*** *hydrophone hub processing system can be programmed to search for these potential threats.*

The three potential threat to ***CG****s from nets of fishing vessels are: 1] trawlers, 2] seiners and 3] drift nets. Of course, the fishing vessel itself is a threat to the* ***CG****. Some of the fishing methods offer low probabilities of interference due to the small cross-section of the deployed equipment. These include vessels deploying sets of hooks on long lines and pots deployed on the bottom.*

Mid-water trawlers and seiners deploying their nets in water depths down to the bottom in coastal areas potentially can capture the ***CG*** *in their nets. Algorithm detections must be able to classify this threat so that the* ***CG*** *can avoid capture by either diving or coming to the surface. When there are more fishing vessels working together the classification is much easier than a single vessel using nets. Speed of these vessels is an important clue since trawlers usually operate at speeds of 3-5 knots continuously. The seiners typically set their nets at about 10 knots and usually use two vessels, but once set, they retrieve their nets while stationary in the water.*

Drift nets are usually deployed by one vessel at 5 to 10 knots and left alone for a while and then retrieved at about the same speed. The threat to a ***CG*** *is entanglement, and the best avoidance measure is to turn away from the detected vessel.*

VI. *DETECTION THREATS TO A GLIDER*

As mentioned previously, a complete knowledge of the local coastal waters is a must for the researcher using ***CG****s. Both ferries and cargo vessels have well-known tracks that are followed, and the times when these vessels are operating in the area of interest is also well known.*

Sources of Coastal Background Noise

The ***CG's*** *hydrophones will be measuring both the self noise of the CG as well as other noise sources. The* ***CG*** *self noise can be a limiting factor, but one of the operational conditions is a sleep mode in which the only operational equipment in use is that of the sensors. Since the* ***CG*** *has an adaptive ballast control system, if water densities are varying in the operational area, the buoyancy engine can be operating, and this can be quite noisy; hence, the use of a sleep maneuver.*

Ambient noise levels in shallow water are typically dominated by near shore sounds, such as harbor activity, swell crashing, crustaceans, and man-made sounds. Further from shore, low frequency sounds from distant shipping may travel for some distance if water is relatively still. Levels below 100Hz are typically from long distance shipping, whereas above that frequency wind-generated waves control the spectrum [14]. And, during times of inclement weather such as rain or sleet or snow, these levels easily dominate the wave generated noise [15]

Detection and Classification Methods

The radiated-noise signatures of various coastal vessels are obtained from various sources and estimated average levels for each type or class of coastal vessel that are expected to be in the ***CG*** *operating area are inputted into the* ***smart***

hydrophone hub processing system *for tonal event detection algorithms.*

Tonal frequencies of cargo vessels and fishing vessels are quite easy to detect as shown in Figure 5 and 6 below.

With estimates of propagation losses for the local waters, for a range of 1,000 meters or less, the received level for a vessel is established. When this level exceeds 140dB, the ***CG*** *is alerted to make some maneuver to avoid this potential threat! However, propagation loss in shallow water can vary between 20 log r and 10 log r and one should use a value of about 15 log r when trying to estimate the range to a particular vessel. With the* ***CG****, the depth of the thermocline can be determined, but even with this knowledge it has been shown that tidal changes can also affect acoustic propagation in shallow coastal waters [16].*

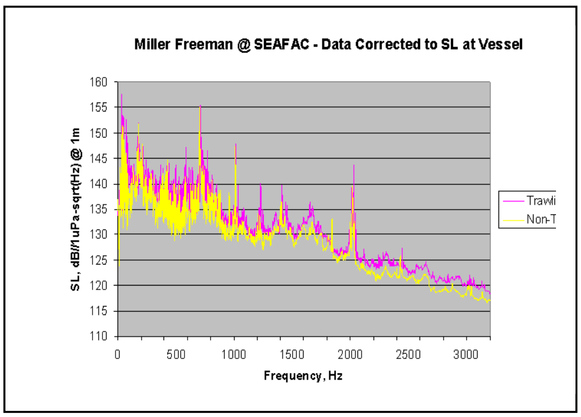

Fig. 5: Radiated-noise signature of a fishing vessel

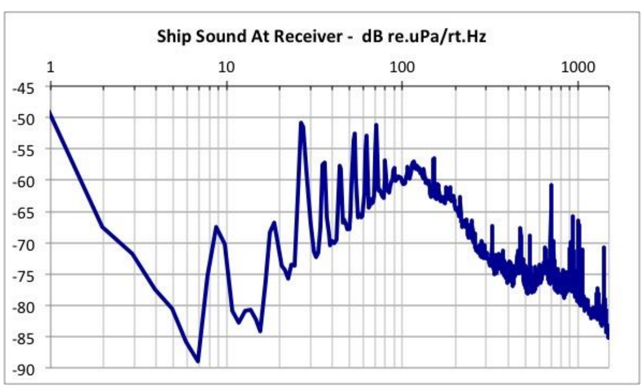

Fig. 6: Radiated noise signature of a cargo vessel.

As shown previously, a second detection and classification method is with the use of DEMON processing for cavitation noise. See Figure 2. This processing element will also be located in the ***smart hydrophone hub processing system.*** *And, it is also expected that the blade rate frequency components detected with DEMON will be higher for fishing vessels, but this hypothesis will be checked during future testing of the proposed* ***smart hydrophone hub processing system.***

Localization Methods

Localization of a threat, whether a fishing vessel, a cargo ship or a ferry, will also require a bearing to that particular threat. Estimates of range can be based on received SPL of a threat, and if this range is less than 1000m then some evasive maneuver must be accomplished. Knowing the range and the bearing, the direction of the evasive maneuver by the CG can be determined. As time progresses, a bearing rate can be established for each target, and when the bearing rate in not changing or changing very little, it is time to make the evasive maneuver.

A key element of the localization method is the ability to obtain both a classification of a fishing vessel and the range, since the logic of the system must determine if the fishing vessel is transiting or is deploying nets. As stated previously, knowledge of the characteristics of the local fishing vessels is a must for the ***CG*** *user!*

CMRE in La Spezia has shown that localization estimates can be made with a single omni-directional hydrophone on a glider [17]. However, use of multiple hydrophones with a beamformer will provide more accurate bearing estimates than that shown in the CMRE paper.

Avoidance Maneuvers

For CG survivability, three specific actions have been identified for a detected vessel: 1] No Action -- continue on defined ***CG*** *mission since the threat is a long distance away, 2] Evade -- since the threat is a medium <1000m, distance away, 3] Surface or Dive -- since a fishing vessel has been detected with their nets deployed.*

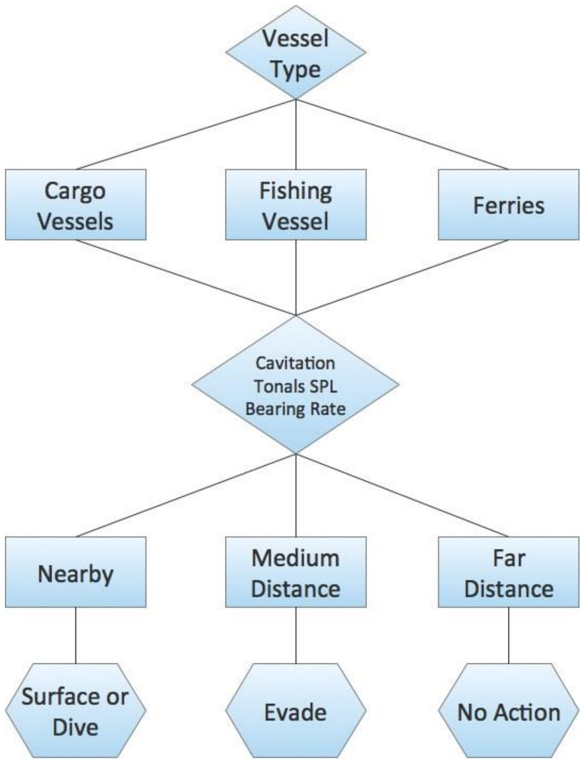

Fig. 3 ***CG*** *Avoidance Logic*

VII. *FUTURE EFFORTS*

Future testing of the ***CG*** *and the* ***smart hydrophone hub processing system*** *is recommended and will be accomplished by the team of Exocetus and Ocean Sonics. This testing will be accomplished in both Alaskan and Nova Scotian waters since these two areas are the locales of the two companies.*

Simulations using data previously collected in the field will allow controlled testing of improved avoidance algorithms.

Self noise testing of the hydrophone system on the ***CG*** *is required to determine the time needed for the sleep maneuver. The ability of the processing system to determine classified threats and track these threats in the presence of one or more targets will be verified using the simulation data, and ultimately live field data.*

VIII. *CONCLUSIONS*

A proposed method for the automatic detection of fishing vessels has been discussed and the maneuvers needed for the ***CG*** *to avoid interference has also been discussed. The proposed approach seems achievable, but needs to be tested thoroughly.*

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