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HAUSDORFF DISTANCE OPTIMIZATION USED FOR UNDERWATER PASSIVE SOURCE LOCALIZATION WITH REAL DATA EXPERIMENT

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Abstract: This paper addresses passive source localization using the TDOAs with comparison between simulations using the acoustic ray path propagation method and recorded signal in real experiment in a tank (from GIPSA-Lab, France), using only one sensor respectively for transmission and reception, not being possible to utilize the beamforming approach. Two new techniques are presented in order to find correct position, in range and depth, 1) the Hausdorff distance and 2) sum of minimum difference. Results in terms of the localization accuracy will be shown with respect of signal-to-noise ratio.

Keywords: *Underwater passive source detection, Source localization; Underwater propagation; Ray path simulation; Hausdorff distance; sum of minimum difference.*

Resumo:*: Este trabalho descreve a localização passiva de alvos usando a comparação dos TDOAs entre os simulados no Matlab, usando o método de propagação acústica ray path e os sinais gravados em um experimento real no tanque do GIPSA-LAB, Franca, usando apenas um sensor na transmissão e outro na recepção, não sendo possível utilizar a técnica beamforming. Duas técnicas novas são apresentadas para achar a correta posição, em distancia e em profundidade, 1) Hausdorff Distance e 2) soma das mínimas diferenças. Resultados em termos de precisão na localização serão mostrados com os relação a signal-to-noise ratio.*

Palavras-chaves:*Detecção passiva subaquática de fontes ; localização de fonte; propagação subaquática; simulação Ray path; Hausdorff distance; sum of minimum difference.*

1. Introduction

This article focuses on a method for underwater source detection and localization, given a sound source measurement of the sound field recorded by a unique underwater hydrophone.

Passive source localization remains one of the major problems in underwater warfare. It allows detecting, classifying, locating and tracking hostile forces during an underwater operation keeping its main goal, being stealthy. Through this new approach proposed in this work, it becomes possible, with two proposed processing techniques, to detect not only the target in horizontal direction of arrival, (which already has been used for the navy), but also in range of the source and in depth.

The first section aims to present a basic understanding of underwater propagation. Ray Path propagation has been used since early 1960s, used commonly for high frequencies and deep water, because it is only valid if the magnitude distances order involved are much greater than the wavelength (BREKHOVSKIKH, 2003).

The second section introduces some techniques that allow locating an unknown source in range and in depth, using the time difference of arrival (TDOA) through the comparison from ray path propagation simulated, and the TDOA recorded.

The third section is shown the measuring setup, and explain how was recorded the data utilized for comparison. The accuracy of each technique is discussed at the end of the paper.

2. Underwater Propagation

The propagation models can be classified into two groups:

- Range dependent, where it is considered the variation of environmental parameters, usually the speed of sound and bathymetry, not only as a function of depth, but also in terms of the distance and azimuth,
- Range independent, where the horizontal stratification of the oceans is assumed, where the variation of environmental parameters is only a function of depth. In these geometries, because only one propagation path is considered, called one-way, there is no oceanographic characteristics that cause the way back (incoming wave) and therefore the solution is based only on the divergent wave (outgoing wave).

In this work we ignore the way back (incoming wave) and we consider a range independent propagation because the variation of environmental parameters are disregarded.

A. Ray propagation

The ray propagation theory is mainly described in (JENSEN F. B., 2011) (KINSLER, 2000). In this article we are interested in how to apply the ray propagation theory to the localization problem. Each ray path suffers small variations of its curvature due to variation of the sound speed profile, according to Snell's law. The received signal is composed of several arrivals that are the time shifted and attenuated versions of the emitted signal. In our work we only consider 3 different groups, which differ by the reflection number on the bottom. Shown in figure 2.

On the first group, zero bottom reflection, second group, one bottom reflection and third group, two bottom reflections. The limit at two bottom reflections is due to high attenuation caused by those reflections that conduct to the level of the signal below the level of noise. The groups composition are: first group (direct path and one surface (S) reflection), second group (bottom (B), BS, SB, SBS reflections), and third group (BSB, BSBS, SBSB, SBSBS reflections). The total of different ray path for short range and using a Munk's sound speed profile, shown on figure 1, counting the 3 groups, is 10 paths and for long range is 8 paths because the first group will not occur anymore, that will be showed below.

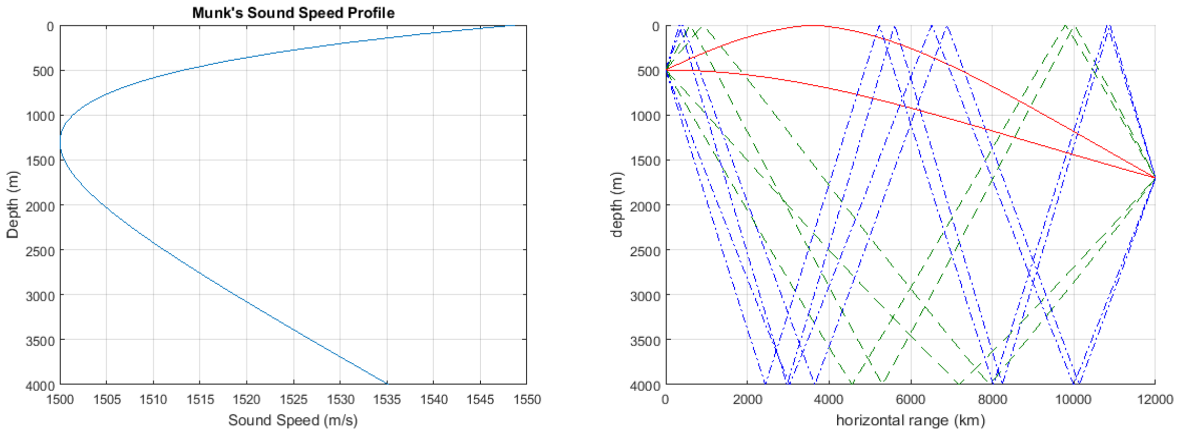

Figure 1-2 - Munk’s sound speed profile - Composition of the 3 groups.

The table 1 shows how the simulations were done and which parameters are being focused in each case.

Table 1 – Set of simulations.

	First Simulation	**Second Simulation**
Type	Arrival time with distance variation	Arrival time with depth variation
Focus	estimate the distance	estimate the depth
Transmitter depth	500 m	500 m
Receiver depth	1700 m	100-3500 m
Distance	1-35 km	2 km
Bottom Depth	flat at 4000 m	flat at 4000 m

For the first simulation, it can be shown on figure 3 until a 13 km range, the total of 10 multipaths, 2 for the first group (red color at 1 km range) and 4 for the second (green color at 1 km range) and 4 for the third group (blue color at 1 km range). After this distance only 8 multipaths are presented because the direct path does not occur anymore due to the ray curvature. It can be noted that each variation in distance results in different TDOA, and the latter reduces with increasing distance. Another conclusion is that for distance localization the TDOA intergroup are more significant, being the reason whereby were utilized for localization in range. The TDOA of the received signal is compared with the simulated one and through this process we can identify the approximate distance from the target.

For the second simulation, it can be shown on figure 4, the total of 10 multipaths for all depths, 2 for the first group (red color at 1 km range) and 4 for the second (light blue color at 1 km range) and third (dark blue color at 1 km range) group each. It can be noted that with increasing depth the TDOA intragroup become more significant due to the dispersion, being TDOA intragroup the reason whereby were utilized for depth localization. Consequently, it becomes easier to count the number of multipath.

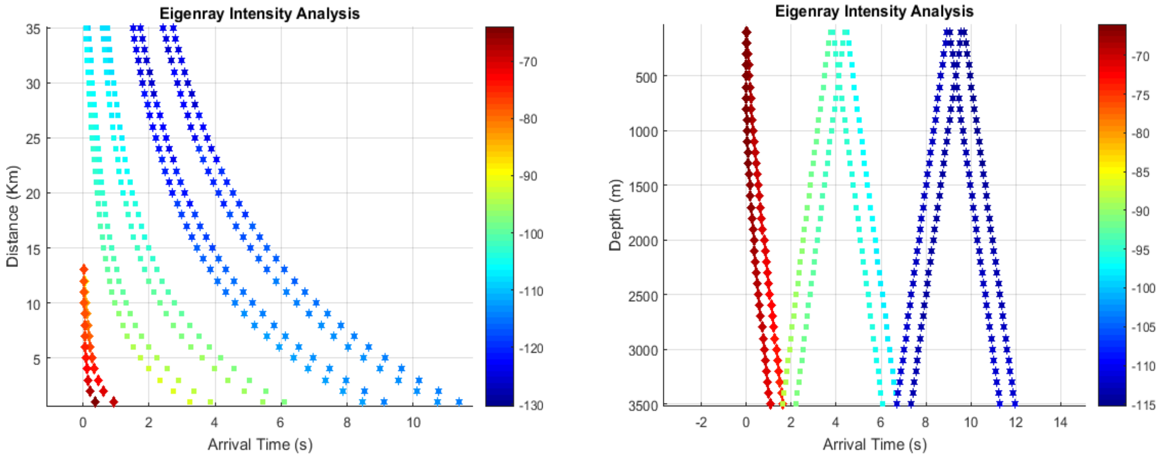

Figure 3 - 4 – Arrival time with distance variation - Arrival time with depth variation.

3. Localization techniques

A. Hausdorff Distance

The Hausdorff distance represents a measure of the spatial distance between two sets of points, and gives an interesting measure of their mutual proximity, by indicating the maximal distance between any point of one vector to the other vector. Once that we are try to localize using this measure, the best results or the most accurately, should give as output the value of zero, that means the correct position. The function $\mathrm{h}(\mathrm{TDOA_s}(\mathrm{d},\mathrm{r}),\mathrm{TDOA_r})$ is referred to as the directed Hausdorff distance from the simulated to the received. It categorizes each arrival time of the simulated according to its distance (difference of time) to the nearest arrival time of the received. The largest of these distances determines the value of $\mathrm{h}(\mathrm{TDOA_s}(\mathrm{d},\mathrm{r}),\mathrm{TDOA_r})$. (D. P HUTTENLOCHER, 1993)

$$\mathrm{h}(\mathrm{TDOA}_s(\mathrm{d},\mathrm{r}),\mathrm{TDOA}_r) = \max_{(\mathrm{d,r})}\{\min_i[|\mathrm{TDOA}_s(\mathrm{d},\mathrm{r})(\mathrm{i}) - \mathrm{TDOA}_r|]\}$$

Equation (A.1)

B. Sum of minimum distance

The Sum of minimum distance also represents a measure of the spatial distance between two sets of points, with the difference that take in count every difference between a set of points instead of only the maximum difference.

$$SMD(\mathrm{d},\mathrm{r}) = \sum_{i=1}^{n} \min_i[|\mathrm{TDOA}_s(\mathrm{d},\mathrm{r})(\mathrm{i}) - \mathrm{TDOA}_r|]$$

Equation (B.1)

4. Experiment in the Tank (GIPSA-LAB)

This experiment was conducted on 14.07.2016 in Grenoble - France, in the tank of the laboratory of GIPSA-LAB at University of Grenoble, whose size is 1.5 meters length by 1 meter width by 1 meter height, (shown in Figure 5 - 6).

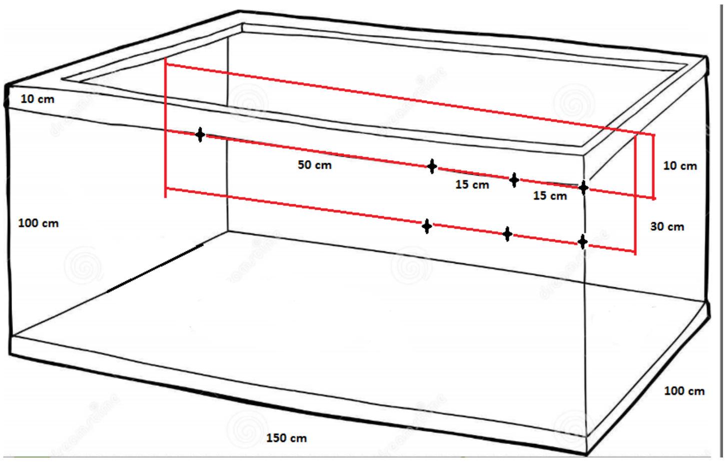

Figure 5 – Measurement setup.

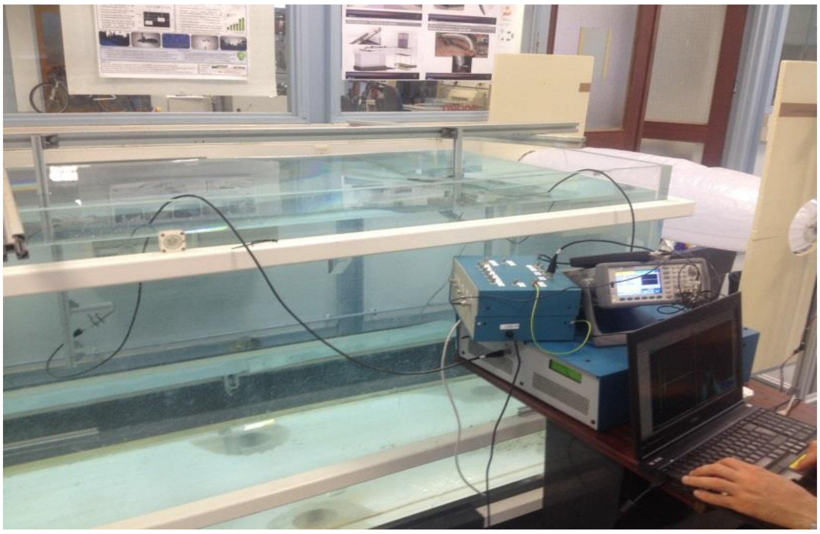

Figure 6 – Equipment utilized for the experiment.

The assembled system was static with 3 different distances, in this article we are focus in a fixed distance and depth. The main objective was to check the simulations made in Matlab, and localize a target now employing real data in a controlled environment, for passive localization using TDOA of different ray paths.

The table 2 shows two signals that were transmitted in this experiment. We were interested to obtain the impulse response from the channel.

Table 2 – Trasmitted signal.

Trasmitted signal		
type	Time (s)	Frequency (Hz)
Impulse	1/25MHz	---
Chirp	100µs	500KHz-1.5MHz

For the transmission, the sensor was located at 0.1 m deep. For the reception, the sensor was located at 0.3 m deep and 0.7 m range, centered horizontally in the tank. Given that the sensors were very directive with bandwidth of 7 degrees, for each set of signals we had to write a package containing 10 different take off angles, if its difference is more than 7 degrees, in order to record all the different ray paths, shown in figure 5. The synchronization of the different signals recorded, with different take off angles, was done by the transmitted signal, so due that it was possible to correctly extract the TDOAs. The amplitude of the signal on figure 7 count with the 2 amplifiers combined, transmission and reception, for each take off angle, as follows at the legend. Due to the small difference of the take off angle, less than the bandwidth of the sensor corresponding a 7 degrees, between 1 bottom reflection and 2 bottom reflection, in some plots we can see both arrival time.

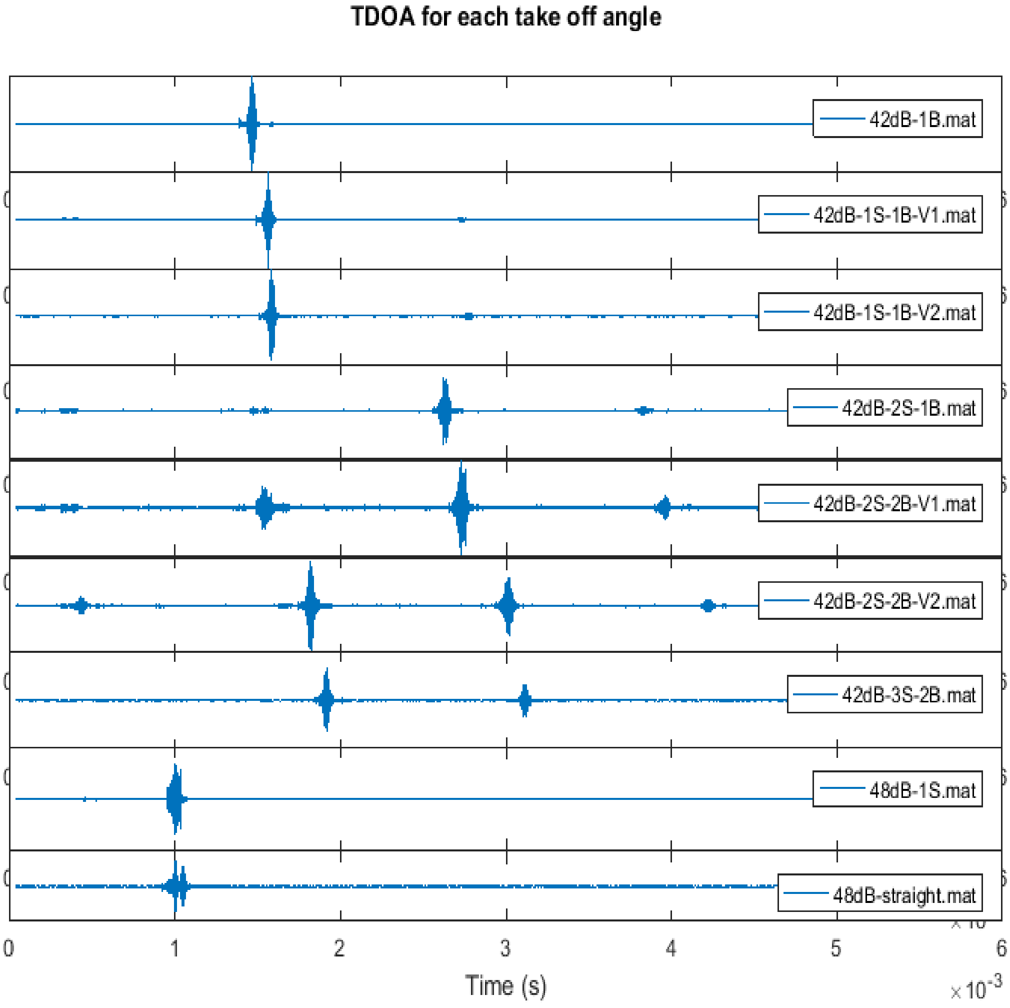

Figure 7 – TDOA recorded of 9 take off angles.

After recorded all different take off angles, with different arrival time corresponding a different paths, these signals were sum in time and after cross correlate with the transmitted singal, shown in figure 8. After taking the maximum local value for each group, that is the arrival time, we applied those techniques introduced above, in order to find the correct position. The signal noise ratio for this measured is 23.69dB.

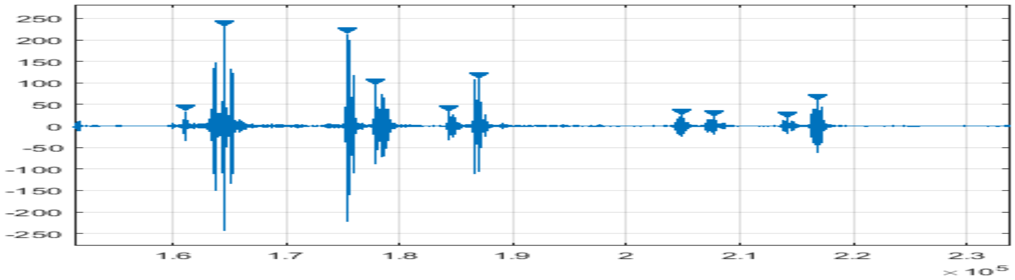

Figure 8 – received signal from sum of different take off angles.

In order to compare the most accurate technique, the results of error was normalize and we kept the same scale after applying the logarithmic scale of the error. The dark blue means the error near to zero that correspond the best result, in both technique we can localize correctly our target with a small variation of error that corresponding the area of the dark blue surface, being the Sum of minimum distance distance more accurate for this measure than Hausdorff Distance, due to its small dark blue area. Shown in figure 9 and 10. The target is located in the red line intersection.

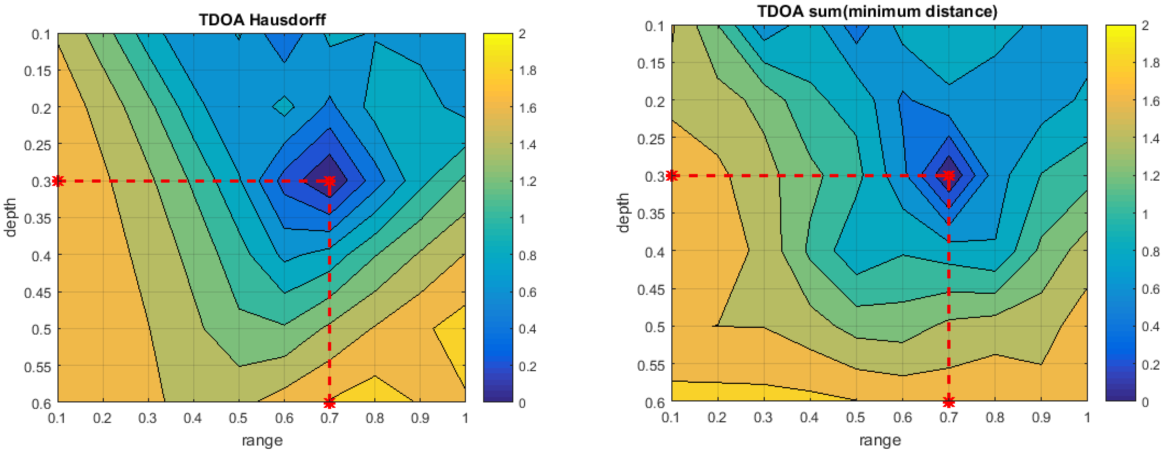

Figure 9 - 10– Error Hausdorff localization - Error sum of minimum distance localization.

5. Conclusion

As we can prove on this work, it is possible localize some target, with a good precision, using a passive approach with only one sensor at the receiver. The 2 techniques utilized a priori for image localization, shown to be very robust for underwater localization. With the experiment made in the tank we could prove the simulations and its consists of an important database for this propose.

The table 3 shows the results after the interpolation with a step of 0.005 m and the error when compared with the real position, 0.7 m range and 0.3 m deep.

Table 2 –Position error.

		TDOA Hausdorff	TDOA SMD
Estimated	Range	0,705	0,69
	Depth	0,26	0,275
Error	Range	0,005	0,01
	Depth	0,04	0,025
Total Error		0,0403	0,0269
Area		0,0011	0,0005
Total Error X Area		4,43E-05	**1,35E-05**

Using the Sum of minimum distance, the precision in depths for this measure had an improvement compared with the Hausdorff Distance. However both results present have satisfactory results. Others measurement need to be done in order to test both techniques to check if the results are consistent.

6. Future works

The next step consists on:

- Combine all these information in order to improve the accuracy with a lower SNR,
- Use a arrays of sensor in order to be able to utilize beamforming technique,
- Measure other environments in order to test others possible configurations

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