Direction of Arrival estimation of underwater acoustic signal via Virtual Steering

Vikas Kumar Singh
Department of Electrical Engineering
Delhi Technological University
Delhi, India
kumarvikas15995@gmail.com

Rashmi
Department of Computer Engineering
Krishna Engineering College
Ghaziabad (UP), India
rashmicp2009@gmail.com

***Abstract*—For a long time direction of arrival estimation to localize the direction of a radiating or reflecting source has been carried out using SONAR technique or using scuba divers which does not give precise location in short time . So development of hydrophone was carried out and there various combinations were used to find the direction of arrival of radiating signal. In the same respect this paper discusses the method of direction of arrival estimation for underwater acoustic signal for various combinations of hydrophones i.e., triplet, linear array, triplet array via virtual steering of directivity pattern of mentioned combinations and GUI.**

***Keywords* —cardioid; direction of arrival; hydrophones; triplet array.**

I. INTRODUCTION

In earlier times in underwater system for detection of enemy submarines and torpedo scuba divers were used who reported by different kind of signal such as flares. This system was not very reliable and thus resulting in loss of human resources as well as cost of ships and submarines. As a result for a very long time now study of underwater acoustic phenomena and their application for surveillance and detection and many more have been carried out. 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 electricity when subjected to a pressure change. Such piezoelectric materials, or transducers, can convert a sound signal into an electrical signal since sound is a pressure wave.

Hydrophones are the principle measurement device to probe acoustic signature underwater. Simplest type of hydrophones is omnidirectional hydrophone which is used to detect presence of acoustic signals but its directivity pattern is '0' so it can not differentiate between signals coming from any direction. Transducers operating in the receive mode - hydrophones - are assembled arrays to improve the response of the array in a desired direction, thereby increasing the signal-to-noise ratio and indicating the direction of a signal source [1].

Hence a combination of omnidirectional hydrophones is used for detection of position of acoustic source i.e. Direction of Arrival this paper discusses about method of virtual steering for various combinations of hydrophones such as triplet, linear array, triplet array. Due to the uniform distribution of sensors, relatively simple signal processing algorithms have been developed for tasks such as direction of arrival (DOA) estimation and beamforming.[2] The virtual steering discussed has been developed using these beamforming equations which gives an edge as it approximates the direction in relatively less time and no human resource is put in danger.

II. HYDROPHONE COMBINATIONS

A. Triplet Hydrophone

Triplet hydrophones are formed by placing three omnidirectional hydrophones on the edge of an equilateral triangle. Fig.1 [3] represents position of elements in triplet hydrophone. Here inter elemental spacing is given by 'a' such that it satisfies following condition $ka \leq \pi/2$ where k represents the wave number of minimum frequency at which the triplet is to be operated[4]. Directivity pattern of triplet hydrophones is cardioids shaped which gives it a view of 120°.But for better detection of source we need more precision which can be bought by using more no of hydrophones.

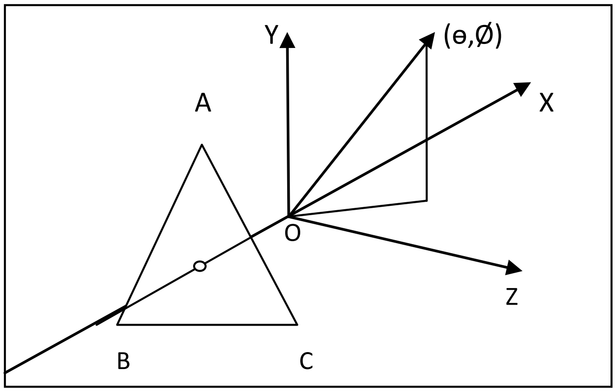
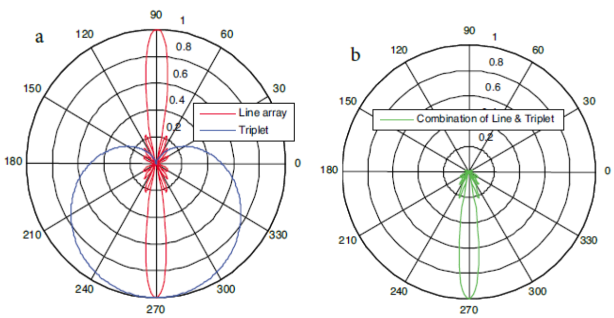


Fig.1 Position of element in triplet hydrophone



(a) (b)

Fig.2 (a) line array and triplet directivity pattern overlap
(b) Triplet array directivity pattern

B. Linear Array

This is one of the most important types of combination as it helps in developing more combinations for better estimation. Linear arrays are formed by placing hydrophones in a straight line at a separation of λ/2 where λ represents the wavelength of min frequency at which the array is to be operated [1]. The directivity pattern of linear array combination is clover leaf shape. The angular resolution of leaf represents with increasing no of elements in the array. The maximum length of array is given by $d = 51\ \lambda/\theta$ (meters) where θ represents desired angular resolution [5]. But linear array suffers from port-starboard ambiguity which needs to be resolved for best estimation results.

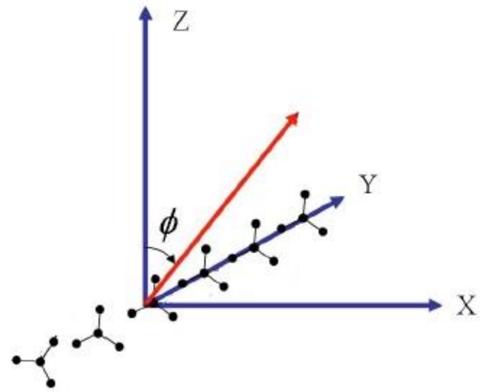


Fig.3 Positon of elements in a triplet array

C. Triplet Array

An alternative is to replace each omnidirectional hydrophone in the array with a set of three omnidirectional hydrophones (i.e., triplets) to form a cardioid response pattern for each triplet element [3]. Fig.2 [5] shows the difference of directivity pattern of all three combinations. In triplet array multiple triplets are aligned together on a common axis see Fig.3 [6] in such way that each element of triplet is spaced by λ/4 and inter triplet spacing is λ/2. As a result the directivity pattern obtained from triplet array consists of single lobe whose precision can be increased by adding more triplets to the array. The ambiguity of port starboard of linear array is solved in this array as there is only one lobe present in this also its angular resolution is better than that of triplet array.

III. DIRECTIVITY PATTERN FOR HYDROPHONES

Directivity pattern is obtained by beamforming of the given combination which are discussed in equations (i)-(iii) where Ø is the steering angle, *f* is operating frequency, *c* is speed of sound in water, α is assigned weight to all elements, *r* is inter elemental spacing.

$$R_c(\emptyset,f)=\sum_{k=1}^{3}\alpha_c^{kj}\exp\left(\frac{2\pi}{c}fi\left(y_{kj}\sin\emptyset-cr_c^{kj}\right)\right) \quad \ldots \text{(i)}$$

Eq.(i) represents the beam forming relation for triplet hydrophone which is a function of minimum operating frequency and steering angle (ϕ). [3] The cardioid pattern (Fig.4(a)) is obtained by plotting Real(R) with respect to ϕ.

$$r(\emptyset,f)=R_c(f,\emptyset)\sum_{j=1}^{N}\exp\left(\frac{-2\pi if}{c}(x_j\cos\emptyset-cr\right. \quad \ldots \text{(ii)}$$

Eq.(ii) represents the beam forming of equation of linear array which is also a function of minimum operating frequency and steering angle (ϕ).[3] Clover leaf pattern (Fig.4(b)) is obtained by plotting Real(r) with respect to ϕ.

$$r(\emptyset,f)=\sum_{j=1}^{n}\exp\left(\frac{-2\pi if}{c}(x_j\cos\emptyset-cr^j)\right)\sum_{k=1}^{3}\alpha_c^{kj}\exp\left(\frac{2\pi}{c}fi\left(y_{kj}\sin\emptyset-cr_c^{kj}\right)\right) \quad \ldots \text{(iii)}$$

The plot of single lobe(Fig.4(c)) is obtained by plotting Real(r) from eq.(iii) with respect to ϕ. This represents the directivity pattern of triplet array.

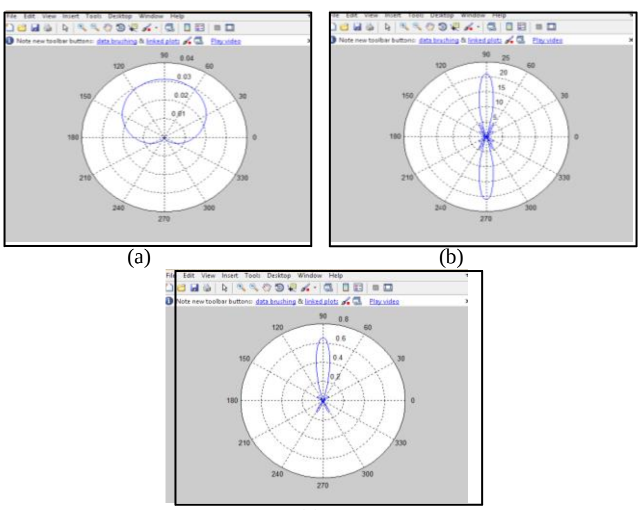
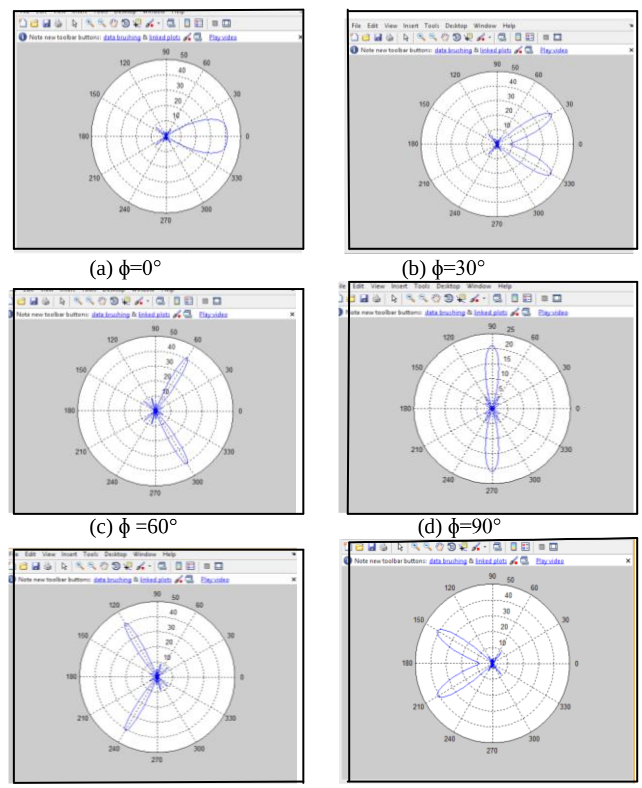

(a) (b)
(c)

Fig.4 Directivity pattern plots using eq.(1-3) for
(a) Triplet (b) Line array (c) Triplet array

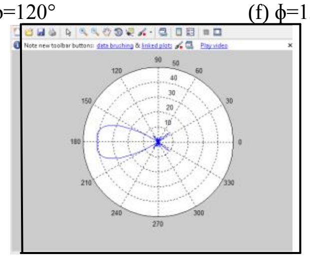
IV. Virtual Steering

The directivity patterns obtained in Fig.4 are used for the purpose of virtual steering. The area around the hydrophone is divided into no. of hydrophones in such a way that only one of the hydrophone will receive signal first if the source is placed in that region. Now the time difference is calculated with respect to each of the hydrophones for all the other elements. Each region around hydrophone is represented by a directivity pattern formed using centrals algorithm on MATLAB [7].

Directivity pattern obtained for Line array is steered (Fig.5) via a GUI and each position represents real areas around the hydrophone. As it can seen that for 0° and 180° there is only a single lobe present (Fig.5(a),Fig.5(g)) as compared to other angle as at these positions ambiguity is not present as time difference increases from first hydrophone to last and only one position is possible for that case. But in rest of the cases port starboard ambiguity resides.


(a) ϕ=0° (b) ϕ=30°
(c) ϕ =60° (d) ϕ=90°

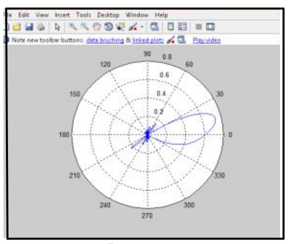
(e) ϕ=120° (f) ϕ=150°



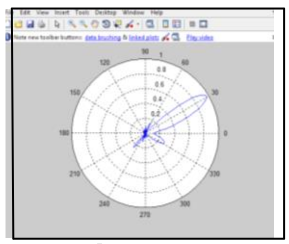
(g) ϕ=180°

Fig.5 Virtual steering of line array from 0°to180°

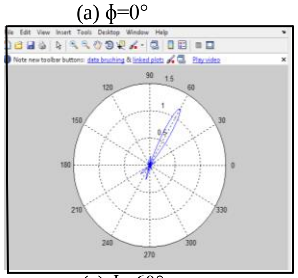
To remove the port starboard ambiguity triplet hydrophnoes are used whose directivity plot steering is represented in Fig.6. It is clearly visible that at steering position 0° and 180° the plot of line array and triplet array are similar. And at other positions one of the lobes of clover leaf has been removed in case of triplet array thus removing the ambiguity.



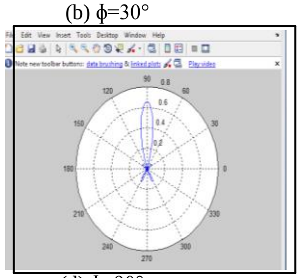
(a) ϕ=0°



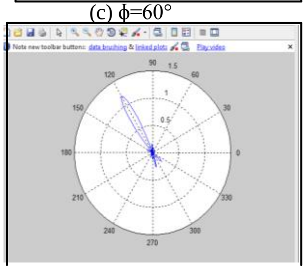
(b) ϕ=30°

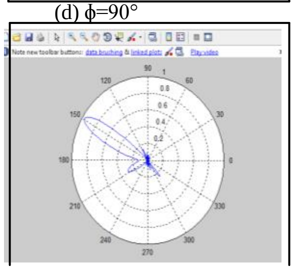


(c) ϕ=60°

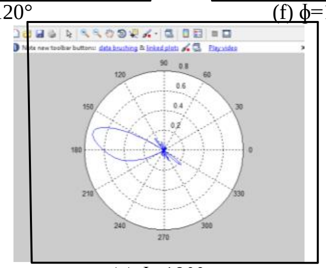


(d) ϕ=90°





(e) ϕ=120° (f) ϕ=150°



(g) ϕ=180°

Fig.6 Virtual steering of triplet array from 0°to 180°

V. Conclusion

This paper has made a simulation result for estimation of direction of arrival using virtual steering. The plot of directivity pattern is steered with respect to angle where each angle represents specified area in 3D world around hydrophone combination. The observation of pattern is closely observed for every angle and result is deduced. Also the comparative result of linear array and triplet array can also be seen from the observation. The results show that linear array suffers from port starboard ambiguity which has been solved using triplet array. Also the precision can be increased by adding no of elements in the array. This method of direction of estimation an be useful for enemy submarine detection and torpedo detection underwater and can help take important counter measures and thus saving valuable human resources.

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