A Determination Process of the Number and Distance of Sea Objects using CHIRP Signal in a Three Sensors Based Underwater Network

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***Abstract*—An inspection of signal processing approach in order to determine the number and distance of objects in the sea is conducted in this paper. In recent researches, a great emphasize is put on determining the number and distance of objects in the sea. But unfortunately, it's a difficult task due to the badly effect of high absorption, long propagation delay as well as dispersion. However, besides SONAR based techniques, some conventional techniques are also familiar to these aspects. In this research, we have proposed a statistical signal processing approach called Cross-correlation, due to its simplicity and convenience for any environment in the sea. The echo effect of CHIRP signal is used here to determine the number and distance of objects in such underwater networks where three sensors are located due to the task. We have verified this proposed theory by a simulation using MATLAB.**

Keywords— sensor, cross-correlation, echo Signal, CHIRP signal, SL case, TS case.

I. INTRODUCTION

In the recent advancement of underwater communication, the underwater wireless sensor networks became one of the most effective areas due to its importance. Both acoustic waves [1], [2] and magnetic waves [3], [4] are used here. In an underwater acoustic network, a great challenge is faced at the time of determining number and distance of objects. Despite having difficulties to determine these values, it needs to perform because of its importance at the field of naval-commercial activities, naval warfare, fishery management etc. Generally, three causes arise behind the difficulties and they are harsh underwater environment, Long propagation delay in under water environment and the dynamic conditions of objects respectively. The conventional ultra sound based techniques are sometimes inefficient due to many causes like the ultra sound acts as a beacon for enemy during warfare. A deleterious effect of ultra sound is implied on the marine lives sometimes. A high cost in this purpose is another cause.

In this research a straight forward method called cross-correlation is familiarized for determination purposes. CHIRP signal, which is also called an angle modulated sweeping signal, is also used here.

Two sensors based determination process of the number and distance of sea objects is described in [5]. But, unluckily, it has some accuracy problems. However, Instead of two sensors network, we have proposed three sensors based network to achieve a better accuracy. Different cases for the sensors distribution are also taken in account.

A framework is build where the number of objects as well as their distance from the sensors is determined. A CHIRP generator is used to generate CHIRP pulses. These pulses have a great likeness to sound pulses.

II. FORMULATION OF CROSS-CORRELATION FUNCTION

For the formulation tenacities, a 3D Network is employed, that contains N number of objects which are evenly distributed. Here, three sensors are employed in two cases: Case 1 – sensors in line (SL) case; and Case 2 – triangular Sensors (TS) case; [6] as shown Fig. 1.

A CHIRP source generates pulses time to time and the objects act as echo generators. The echo signals from the objects are received by the sensors first and then, these signals are summed by each sensor and finally produce a composite signal. Lastly, however the required CCFS are created through the cross-correlation of these three composite signals.

The 3D space as a cube is considered where the dimension of the cube is equal to the sphere diameter. The sensors H_1 , H_2 , H_3 and an object called N_1 are located at (x_1 , y_1 , z_1), (x_2 , y_2 , z_2), (x_3 , y_3 , z_3) and (x_4 , y_4 , z_4).

Distance between sensors H_1 and H_2

$$d_{DBS_{12}} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

Distance between sensors H_2 and H_3

$$d_{DBS23} = \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2 + (z_2 - z_3)^2}$$

Distance between sensors H_3 and H_1

$$d_{DBS_{31}} = \sqrt{(x_3 - x_1)^2 + (y_3 - y_1)^2 + (z_3 - z_1)^2}$$

At SL case, $d_{DBS_{12}} = d_{DBS_{23}} = d_{DBS}$,

which implies that two CCFs are possible.

At TS case, $d_{DBS_{12}} = d_{DBS_{23}} = d_{DBS31} = d_{DBS}$,

which implies three CCFs are possible.

We Consider that the echo signal that comes from N_1 is $S_1(t)$, which is finitely long. Earlier, the signals received by H_1, H_2 and H_3 are respectively:

$$S_{r11}(t) = \alpha_{11} S_{11}(t - \tau_{11})$$

$$S_{r12}(t) = \alpha_{12} S_{12}(t - \tau_{12})$$

$$S_{r13}(t) = \alpha_{13} S_{13}(t - \tau_{13})$$

where α_{11}, α_{12} and α_{13} signifies attenuations as a result of absorption and dispersion in the medium, τ_{11}, τ_{12} and τ_{13} are the corresponding time delays for the echo signals to reach the sensors and last of all S_p is the speed of wave propagation in the water. [6]

For SL case, the CCFS are:

$$C_1(\tau) = \int_{-\infty}^{+\infty} S_{11}(t) S_{12}(t - \tau_{11}) d\tau$$

$$C_2(\tau) = \int_{-\infty}^{+\infty} S_{12}(t) S_{13}(t - \tau_{12}) d\tau$$

Now for TS case the additional CCF is:

$$C_3(\tau) = \int_{-\infty}^{+\infty} S_{13}(t) S_{11}(t - \tau_{13}) d\tau$$

We need to take the total received echo- signals so that we can find the CCFs for *N* number of nodes.

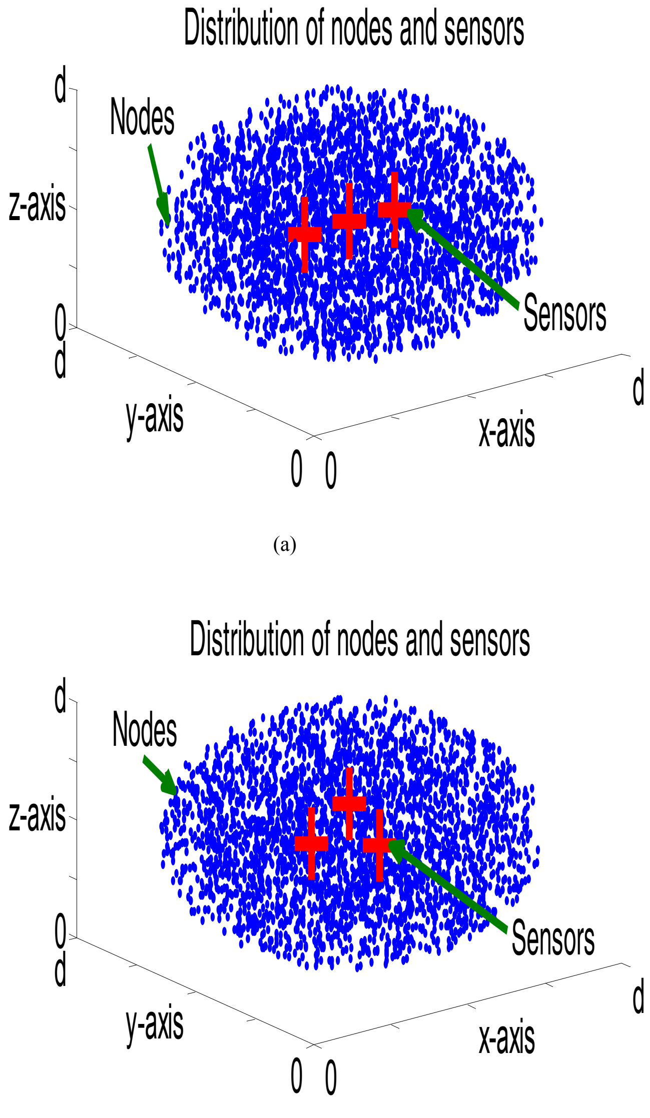


Figure. 1. An underwater network node distribution containing *N* number of transmitting nodes for (a) SL case; and (b) TS case.

Now, the received composite signals by H_1, H_2 and H_3 are:

$$S_{rt1} = \sum_{j=1}^{N} \alpha_{j1} S_j(t - \tau_{j1})$$

$$S_{rt2} = \sum_{j=1}^{N} \alpha_{j2} S_j(t - \tau_{j2})$$

$$S_{rt3} = \sum_{j=1}^{N} \alpha_{j3} S_j (t - \tau_{j3})$$

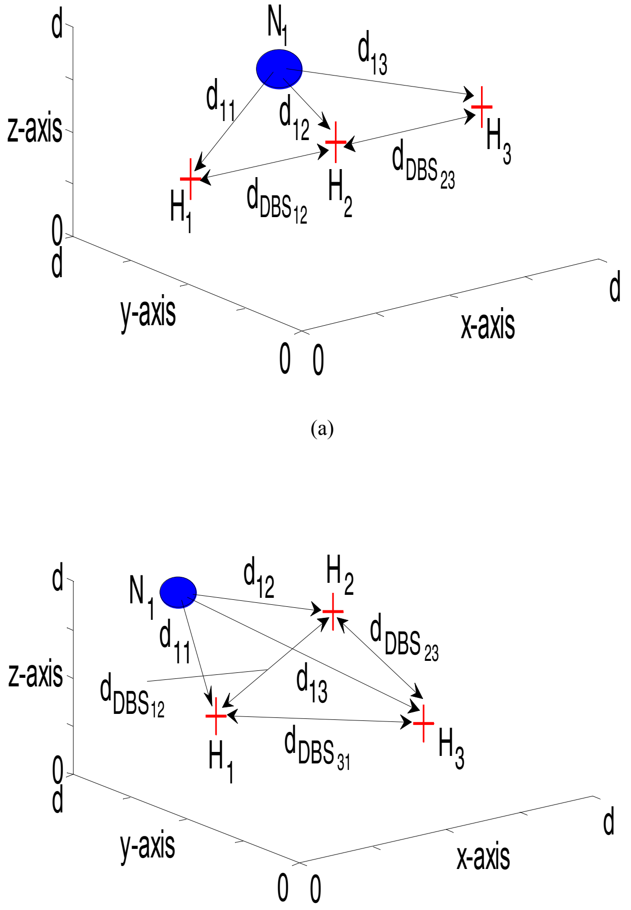
And so, the total CCFs are (for SL case):

$$C_{12}(\tau) = \int_{-\infty}^{+\infty} S_{rt1}(t) S_{rt2}(t-\tau) d\tau$$

$$C_{23}(\tau) = \int_{-\infty}^{+\infty} S_{rt2}(t) S_{rt3}(t-\tau) d\tau$$

For TS case the additional CCF is:

$$C_{31}(\tau) = \int_{-\infty}^{+\infty} S_{rt3}(t) S_{rt1}(t-\tau) d\tau$$

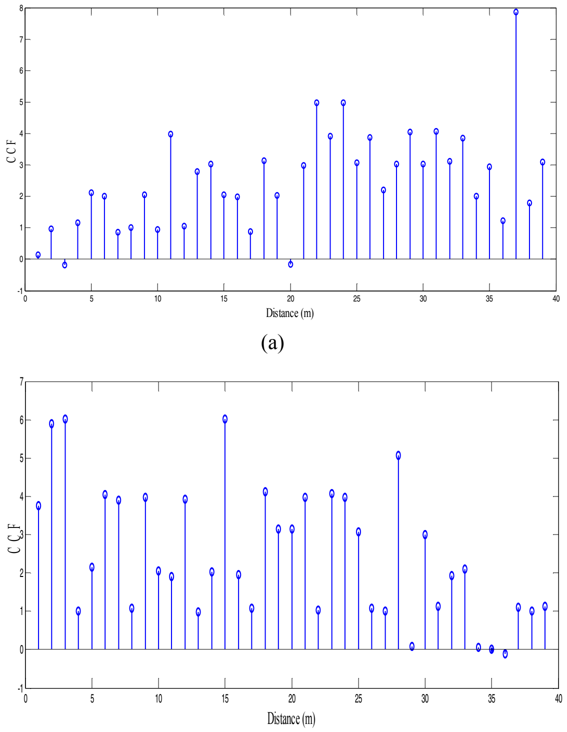


(a)

(b)

Figure 2. Three sensors (+) based underwater network and an object N_1 designed for (a) SL case; and (b) TS case.

Now, a series of delta functions are created through these. Here, $\tau = d_{DBS} / S_p$.



(a)

(b)

Figure. 3. The cross-correlaton bins, b used for (a) SL case; and (b) TS case.

III. DETERMINATION OF NUMBER AND DISTANCE OF OBJECTS USING CROSS-CORRELATION FUNCTION

In the past, the node estimation process in underwater was performed using Cross-correlation Function. [7, 8, 9]

That estimation technique was based on Gaussian signal which was used for node estimation. However, that estimation was performed for two cases:

- Equal transmitted power or ETP
- Equal receive power or ERP

We can epitomize the object determination as a certain example of estimation by means of Gaussian signal. Nevertheless, in this case, we cast-off CHIRP signal for this estimation. In this instance, a CHIRP Generator is used to transmit CHIRP Signal and echoes (CHIRP) from the objects are received by receiver (sensor).

A. CHIRP Signal

A swept-frequency signal named CHIRP Signal is a type of signal which has a time varying frequency. We can express it like:

$$X(t) = A * \cos(2 * pi * ((f_2 - f_1)t^2 / (2 * d) + f_1 * t + P))$$

where f_1 signifies the starting frequency in Hz, f_2 signifies the ending frequency, d indicates time duration in seconds, P indicates the starting phase, and A is the amplitude. [5]

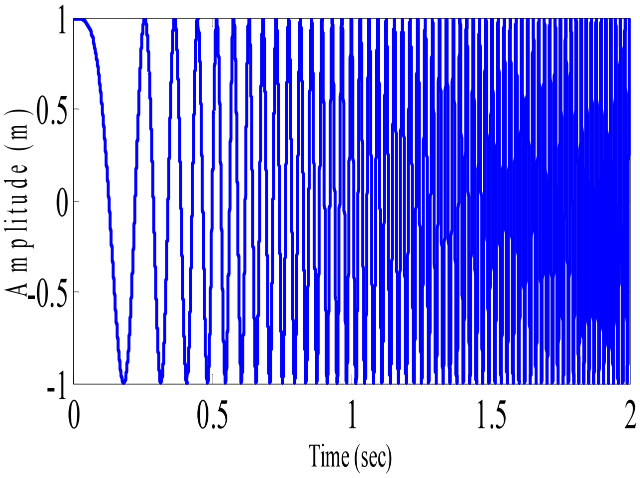


Figure 4. CHIRP signal

B. *Determination of Number of Objects*

Assumption:

- The echo signals are equal in power
- The objects are distributed in 3D Space

Using statistical expression, calculating CCFs to compute the standard deviation and mean is quite tough. On the other hand, cross-correlation technique is used like the problem of probability. This makes the analysis fairly easy. It is conspicuous that the mean, μ, standard deviation, σ of the CCFs and the sum are reliant on signal strength. And if the exact signal strength is known, these may be used. But this is not practical at times. On the other hand, the ratio of standard deviation to the mean of the CCFs, R, is free from reliance on signal strength. Here, it is taken as the determination tool for determining the number of objects. At this research, at first we show that R is related to N and finally we will try to show it through simulation. In Figure.5, a setup for experimental purpose is proposed for the determination of Objects using CCF. The experimental setup is similar to the presentation in Conti et al. (2006), [10]. The experiment was implemented in a tank and for a small number of Objects but the same setup can be used for determination of large number of Objects in the deep Sea. At this premises, the echo signals (CHIRP) are used.

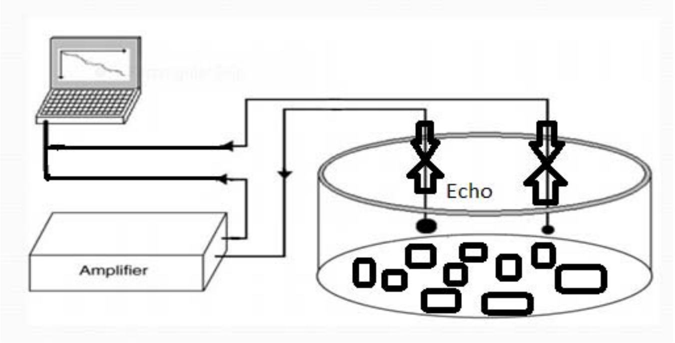


Figure 5. A setup for experimentation to determinate the number of objects using CCF.

C. *Number of objects from theory*

First of all, we have to determine the number of the objects. For our determination resolves, we use the ratio of standard deviation σ, to the mean μ. The ratio of Standard deviation to the mean is expressed as in the bellow: [9]

$$R = \sigma / \mu = \sqrt{\frac{(b-1)}{N}}$$

Now, b corresponds to the number of bins, can be well-defined as twice the number of samples between the sensors (NSBS), m, minus one. For SL case, the final ratio of the standard deviation to the mean can be found from the average of R_{12}, R_{23}. This indicates that two CCFs are used.

$$R^{2CCF}_{Average} = \frac{R_{12} + R_{23}}{2}$$

For TS case, the final ratio of standard deviation to the mean is obtained from the average of R_{12}, R_{23} and R_{31}. Here, three CCFS are used.

$$R^{3CCF}_{Average} = \frac{R_{12} + R_{23} + R_{31}}{3}$$

Here, we know b and at the same time we can evaluate $R^{2CCF}_{Average}$ and $R^{3CCF}_{Average}$. A point to be noted that b a function of distance between sensors, d_{DBS}, sampling rate, S_R and speed of propagation in water, S_P.

So finally we can determine the number of objects N by using the two equations above.

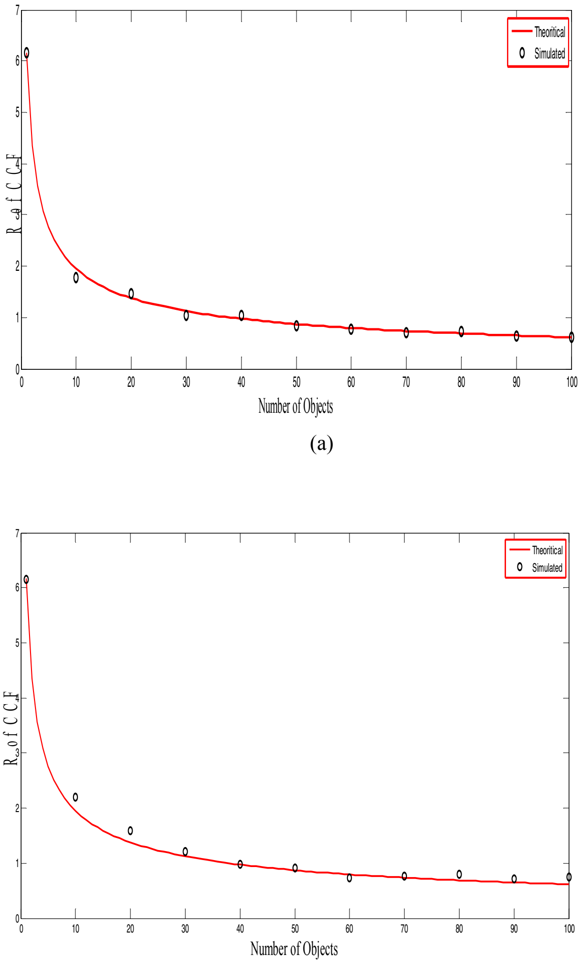
D. *Number of objects from Simulation*

As the number of bins, b is a function of distance between sensors, d_{DBS} .sampling rate, S_R and speed of propagation,

S_P, infers that b is fixed for a particular case in which the sampling rate , S_R, speed of propagation in the water, S_P, and distance between sensors, d_{DBS} are fixed . So we can extract that, the final ratio, R, shows an inversely proportional relation to the square root of the number of objects, N. So

$$R = c / \sqrt{N}$$

where, a known constant, c ($\sqrt{b-1}$) depends on occurrence between sensors, d_{DBS}, speed of propagation in the water, S_P sampling rate, S_R. As a result, the number of objects can be determined using simulation, where we have to calculate R accordingly to the simulation.



(a)

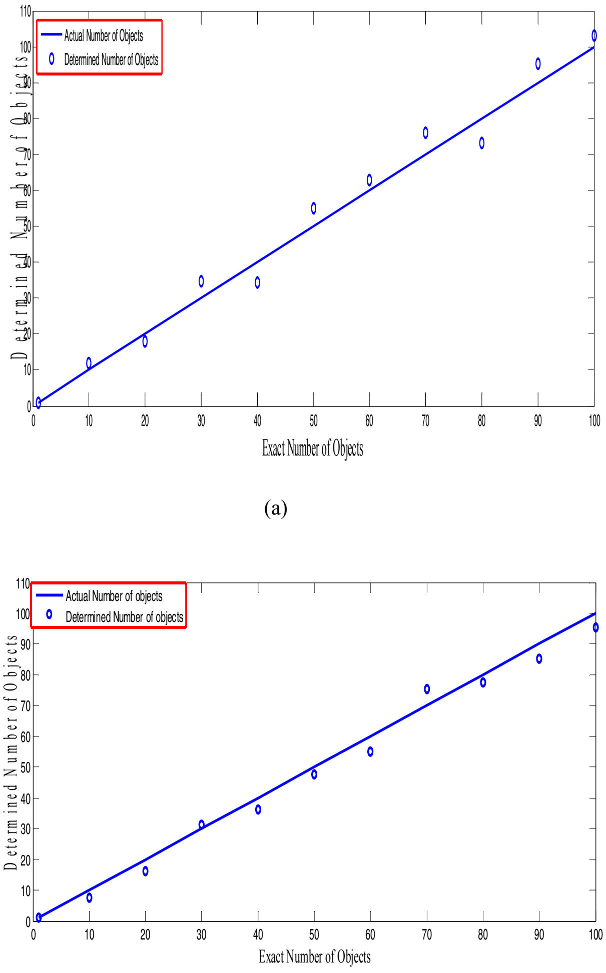
(b)

Figure 6. Ratio of Standard deviation to the Mean of CCF from theory and simulation for (a) SL case; and (b) TS case with bins, b =39 and d_{DBS} =0.5m.

Thus the final expression can be written:

$$N = \frac{b-1}{R^2}$$

From here, as the bins, b is well-known from experimental setup, R is achieved from the simulation, the object number N is found using the equation above.



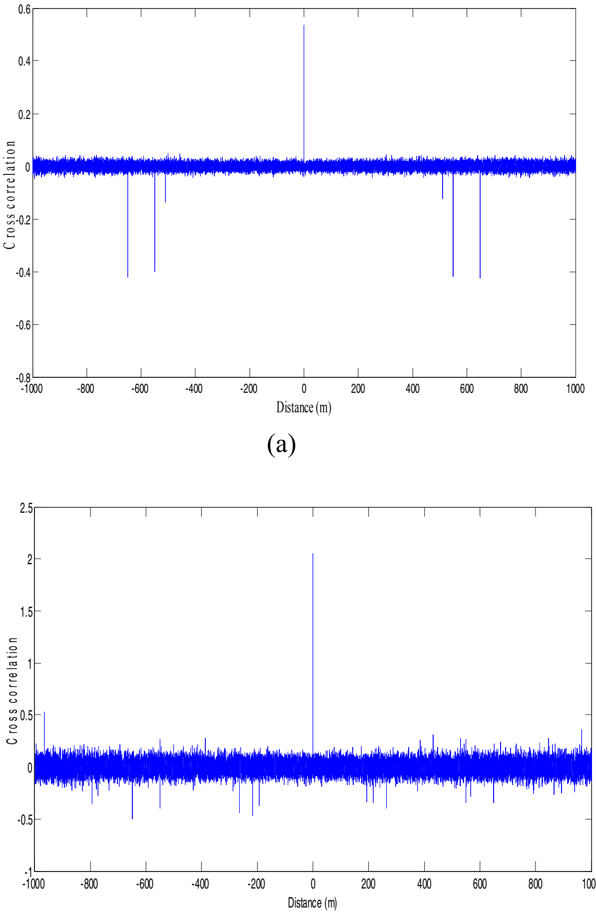
(a)

(b)

Figure 7. A variation to the determined number of objects and the actual number of objects for (a) SL case; and (b) TS case.

E. Determination of distance from simulation

The second step is for determination of distance of objects in an underwater network. In order to determine the distance, we generate CHIRP pulses using CHIRP generator to the objects. The pulses are then transmitted for several times according to our requirement. In this incident, we will know the frequency and wavelength of the pulses. When the signals come back from the objects as echoes, we can determine these according to their wavelengths and frequencies. However, a computer is used to record the echo pulses as Figure. 5. After receiving the pulses, we will cross-correlating them and determine the cross-correlation function. The recorded pulses are good indicators of the object distances. Finally, the plot of cross-correlation functions verses distances is a direct indicator of different object position and distances.



(a)

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Figure 8. Different pulses represent different location of objects for (a) SL case; and (b) TS case.

From Figure. 8, it is seen that, the cross-correlation functions are found at specific positions such as (500m, 540m, 650m at sensors in line case) positions. For triangular sensors case the spike of the pulses are found at several positions such as (210m, 260m 680m etc.). These signify a good indicator of their distance parameters because the plots show a result of cross-correlation functions at different positions of objects, where both are correlated to each other.

IV. CONCLUSION

To the sum up, In the Sea, the estimation process of number of objects is difficult to use existing techniques due to some obstacles such as harsh underwater environment and mostly human interactive. So, here we proposed cross-correlation method and also used CHIRP signal which one permits high resolution on time axis. For this reason it is greatly suitable for ranging. However, this technique has some limitations such as our consideration of receiving power is equal and the delays are presumed to be integer. But, after all this proposed method is not human interactive. That is why; it is convenient to determine the number as well as distance of objects in the sea through this process.

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