Performance of underwater source separation using narrowband and broadband signal at mini underwater test tank with varied in salinity and temperature

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Abstract. SONAR is one of underwater communication by using acoustic wave which having smaller attenuation value in underwater than others wave. However, SONAR received mixing information from the source caused by noise from ship, offshore activity and seismic noise. Therefore, in this paper we propose a method using Independent Component Analysis (ICA) to separate the mixing signal to get the desired signal. Sound source separation is performed at mini underwater test tank in Vibration and Acoustics Laboratory using the same number of source and sensor configuration. The variables are varied based on salinity, temperature and sensor displacement changes. The separation process was carried out using TDICA, FDICA, and MSICA methods. From the mixed sound recording results obtained the best separation results using FDICA and MSICA methods for each variable change. The average MSE score was 0.0890 and 0.0899 for the FDICA and MSICA methods, while for the TDICA method the average score of MSE 0.1692 was obtained. Along with the increase in distance and changes in propagation medium, the quality of the separation is decreased.

1. Introduction

SONAR is one of the application of underwater communication by using acoustic wave which having smaller attenuation value in underwater than others wave. However, SONAR received mixing information from the source caused by noise from ship, offshore activity and seismic noise. Therefore, in this paper we propose a technique to separate and distinguish between the information signal and the unwanted signals received by the receiver. BSS (Blind Source Separation) is a technique to model the selection of signal from the mixed signal where the initial condition is unknown. In the previous research has been conducted the application of sound separation using ICA (Independent Component Analysis) to simulate the separation of underwater acoustics signals varied in several source and algorithm. The result shows the cross-correlation value in 0.98 which shows that the mixed signal can be separated [8]. Also, the separation of mixed signal has been conducted in semi-anechoic underwater test tank by using TDICA (Time Domain Independent Component Analysis) method. The simulation shows the better result with MSE value about 3.8x10⁻⁸, while in the separation of mixed signal in underwater test tank shows lower result in MSE that is 0.01 below the simulation result [9].

Hence, in this paper we will discuss the method to separate unknown mixing signals by using narrowband and broadband signal as a stimulus in the mixing signal with varied of temperature changes.
and salinity. The experiment will be conducted in semi-anechoic mini underwater test tank in Vibrastic Laboratory, Department of Engineering Physics, ITS, Indonesia.

This paper contains of four sections, the first section will describe the background and purpose of the research. Section 2 explains the method used in this research, section 3 describes the results of separation signal, and ends with the conclusion and the future work.

2. Method

2.1. Test Signals

In this experiment, according to ICA estimation, the test signal should be independent and non-Gaussian. The Gaussian distribution allowed only on one of the test signal. The independency of the mixed test signal can be known using covariance value of two signal. While kurtosis is used to examine non-Gaussianity of the test signal. Table 1. showed sourced sound mixture with multi input and multi output. Narrowband and broadband signal was used as source signal with five variations of mixed signal. Signal tone signal with frequency 500 Hz and 800 Hz are categorized as narrowband signal. Signal of ship noise, sonar ping and broadband (pure-tone with frequency 500 Hz, 700 Hz, 900 Hz, 1100 Hz and 1300 Hz which generated simultaneously) are categorized in broadband signal.

| Signal 1          | Signal 2          | Multi Output       |
|-------------------|-------------------|--------------------|
| Pure-tone 500 Hz  | Pure-tone 800Hz   | Narrowband         |
| Pure-tone 800Hz   | Ship Noise        | Broadband          |
| Ship Noise        | Sonar Ping        | Broadband          |
| Broadband         | Ship Noise        | Broadband          |
| Sonar Ping        | Pure-tone 800Hz   |                    |

2.2. Experimental Set-up

The experiment conduct at test tank dimension is 2 x 1 x 1 in meter from tempered glass and covered inside by corrugated sponge to reduce the echo and possible reflection from signal that we generated. In this experiment, we are using hydrophone array as sensor. Hydrophone array configuration will achieve spatial selection, strengthen source propagation from a particular direction and weaken the source propagation from the other direction. The position of hydrophone array on mini underwater test tank should be considered to avoid spatial aliasing. Distance of each hydrophone is determined by equation

\[ d < \frac{\lambda_{\text{min}}}{2} \]

where \( d \) is the distance of array component, while \( \lambda_{\text{min}} \) is the minimum wavelength from the maximum signal frequency. Then, the sensor’s distance should be smaller than the wavelength from upper and lower frequency limits.

This experiment used 500 Hz as the lower frequency and 1300 Hz for upper frequency. The allowed distance of the sensor according to wave propagation in the mini test tank should be smaller than 45 cm. Therefore, we used three variations in each hydrophone distance that is 10cm, 20cm, 30cm.

The mixed sound source recording configuration was using two speakers and two hydrophones set as figure 1. There used three distance variation between speaker and hydrophone in 80 cm, 100 cm and 150 cm. Referring to Indonesian shallow sea water characteristic, salinity level and temperature difference is considered in this experiment. We used 3.5% salinity level and with temperature of 9°C as same as Indonesian shallow sea water characteristic. In this experiment, we also performed variation in temperature difference and salinity level to know the changing characteristic of the method used. The temperature difference variation was using 9°C, 13°C, 16°C, 19°C, 22°C, 15°C, and 28°C and 3.1%, 3.2%, 3.3%, 3.4%, and 3.5% was used for the salinity level. Duration of the data is 4 second with sampling frequency 16.000 Hz.
2.3. Independent Component Analysis (ICA)

Data processing for separate the mixed signal was done by using ICA method. Before the ICA estimation phase, there are pre-processing stage which consist of centering stage and whitening stage. The algorithm model for sound separation mixture as $X(t) = AS(t)$ where $X(t) = (x_1(t),...,x_j(t))$ is observation signal, $A$ is environment mixing matrix and $S(t) = (s_1(t),...,s_n(t))$ is source. Then for gain $S(t)$ the model become, $Y(t) = WX(t)$ where $Y(t)$ represent source expectation ($Y(t) \approx S(t)$), $W$ is environment de-mixing matrix ($W \approx A^{-1}$) and $X(t)$ is observation signal.

Time-Domain ICA (TDICA). Separation of mixed sound using TDICA is done by directly give the mixed input signal which recorded in the anechoic test tank. The input and the reconstructed signal will remain in the time domain ($t$), illustration of TDICA method can be seen in figure 2. TDICA method will minimize the nonnegative cost-function which will be minimum if cross-correlation value is zero [7]. The estimated of separated signal can be obtained by multiplying the observation signal with the $w(z)$ filter.

Frequency-Domain ICA (FDICA). The separation using FDICA method is done by transforming the input mixed signal from time domain into frequency domain as illustrated in figure 3. The transformation was using Fast Fourier Transform (FFT). Once obtained the reconstructed signal of the separation result, then returned into time domain using Inverse Fast Fourier Transform (IFFT). Separation of signal with FDICA can simplify the sum of convolution into instantaneous sums, it makes the separation process will easier to achieve convergence during the iteration.

Multistage ICA (MSICA). The MSICA method for separate the signal is complete by combining processes from FDICA and TDICA. The mixed signal used as input will be processed first by FDICA, after that the FDICA separation result will be input for TDICA. Then the output of separated signal from TDICA will be the estimated signal of MSICA.
In order to evaluate the estimated of separated signal, here used mean square error (MSE) and signal to interference ratio (SIR). The smallest MSE value means the estimated signal is more similar with the original signal. While the greater SIR value gives better estimated signal quality.

3. Result and Discussion

3.1. Results of Data Processing

The requirement of ICA method for estimated signal is independent and non-Gaussian test signal. The independence of test signal performed by finding its covariance value, the closer covariance value of two test signal to zero means that the signal has strong independence characteristic. The independence test result shown that almost all test signal meet the independence assumption. The highest covariance value is found between signal sonar ping and 800 Hz tone while the smallest value is in signal ship noise and broadband signal. Other conditions besides the signal must be independent also not included in the Gaussian distribution. It performed by the value of kurtosis and negentropy of each test signal. Signals that have a kurtosis value equal to three and a negentropy value close to zero will not be used. The negentropy calculation result showed that the signal fulfill the non-gaussian criteria. The test signal should meet both ICA criteria to make an optimal signal separation.

3.2. Mixed Sound Separation

Pre-processing stage consist of centering and whitening. The centering process was given to input signal \( x \). Then, the determination of whitening matrix was obtained by give the value of eigen value and eigen vector on covariance matrix. The separation of mixed sound in this study is grouped by method, distance variation and propagation medium change. The evaluation of the separation performance can be seen from the average MSE value of the overall signal estimation. MSE is one way of knowing the quality of an estimation signal compared to the original signal. Figures 4 and 5 show the mean comparison of MSE based on salinity medium and temperature change with variation in the separation method, the distance between the sensor and the distance between the sensor and the source. In terms of separation method, separation performance using TDICA method is worse than FDICA and MSICA.

In figure 4 and figure 5, the MSE value tend to be higher along with the increase of distance between sensors and the distance between sensors and source that is equal to 0.199. The best performance for TDICA, FDICA and MSICA method achieved in the distance between sensor of 10 cm and with distance between the sensor and source in 80 cm for both on salinity of 3.1% and in temperature of 9°C. The further distance between the sensor and the distance between sensor and source will give bigger MSE value. The MSE value for both FDICA and MSICA method only have slightly difference, but in TDICA method give big difference as the distance between the sensor and source increases. This is because of the result of TDICA affected by the delay time for about 0.0014 second which obtained from the data retrieval.

![MSE Comparison of 3.1% Salinity](image_url)
The separation of mixed signal, sonar ping signal and ship noise signal, have the best MSE value among the other mixed signals. Figure 6 show the MSE value comparison of the mixed signal with variation in distance between sensor and source also with variation in salinity level of 3.1% to 3.5%. While in figure 7 can be seen the MSE value comparison of the mixed signal for sensor and source difference and variation in temperature change. Both using TDICA method. It can be seen that the performance of separation signal getting worse as the salinity level and temperature difference increase, shown by the MSE value getting bigger. This caused by the medium density which affecting the velocity of the sound, so there is a delay time for sound from source to sensor. The increase of salinity level will cause the sound propagation velocity decreasing. The same result also obtained in every temperature change, from the lowest temperature to near room temperature, which give increasing MSE value. With the increase of the mean value of MSE for TDICA method on each change of propagation medium and the difference of distance between sensor and source indicates that the separation quality decreases for each variable change. The quality decrease also occurs almost every mixed signal used as well as other separation methods.

The separation of mixed sounds in the anechoic test tank uses several test signals that are mixed in different propagation mediums. Salinity and temperature changes are the control variables in this study where salinity and temperature changes are conditioned near the true state of the ocean. In the case of this mixed sound separation using three separation methods that are TDICA, FDICA and MSICA. In some test signals used there are signals that cannot be completely separated, but some mixing components can be removed. Of the three methods of separation of quality obtained from each distance either between sensors and sensors to the source has a quality difference. The TDICA method has a decreasing quality when there is a change in distance and variables as shown in Figure 5 and 6.
4. Conclusion
In this paper, we performed separation of mixed signal with variation in propagation medium and position of the sensor in anechoic underwater test tank. Among the methods used in separation, the FDICA method is superior to other methods. The average value of MSE FDICA was 0.0890, while for TDICA and MSICA methods were 0.1692 and 0.0899, respectively. Changes in some variables such as distance and medium propagation can affect the performance of mixed separations. The further distance between the sensor will decrease the separation result. And also, the higher salinity level and temperature difference give separation result decrease.

For the future work will be conducted the experiment with variation in the angle of the sensor and source. Then used other algorithms to provide approximate direction of the signal arrival and increase signal level which reduced due to noise and reverberation.

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