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Passive Time-Delay Estimation

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RESUME

SUMMARY

Estimation of time delay between the signals at two spatially separated sensors insoniated by the same source leads to bearing/range estimation in passive sonars. In order to improve the statistical predicability of such an estimate many pre- and post-processors are used in the time delay estimation systems. In this paper various pre and post processor systems are compared on the basis of variance and probability of success. An alternate method of pre processing is suggested. Simulation results on various processors is presented.

Introduction

Localisation and tracking of a target (Source) in passive sonar environment is achieved by estimating the time delay between the time of arrival of signals at two or more spatially separated sensors. This time delay is estimated by cross correlating the signals, through frequency domain techniques like FET or otherwise, at two sensors. The peak of the correlation yields the required time-delay.

The variance of the peak of correlation depends on SNR, the correlation between the additive channel noises and the presence of tonal components in the signals. Various pre and post processors have been suggested to reduce the variance of the peak and thus improve the performance of the estimation system.

This paper suggests a method of smoothing the cross spectrum by a m-point running average before inverse transforming the spectrum. The smoothed spectrum after averaging for a N-point spectrum p_i, i = 1,2 -- . N is

$$q_i = \sum_{j=i}^{m+i-1} \frac{p_j}{m} \qquad i = 1,2,\text{--} . N-m+1$$

$$= p_i , \qquad i = N-m+2, \text{--} . N$$

The proposed system is compared with various other processors and relative evaluation is obtained on the basis of variance of the peak V_p from the true delay D defined as

$$V_p = \sum_i \frac{u_i - D}{M} f_i$$

where M is the total number of experiments, f_i the frequency of occurance of the random variable u_i, the peak of the correlation with $\sum_i f_i = M$. The various processors are also compared on the basis of probability of success where success is defined as the number of experiments that given the peak within ± 2 samples of the ture delay D.

Simulation of the various processors like SCOT, PHAT, HB and ECKERT were all conducted for SNR ranging from 5dB to -10dB and were based on 34 experiments.

Preliminaries

Let $x_1(t)$ and $x_2(t)$ be the two incoming signals to a passive delay estimation system with

$$x_1(t) = s(t) + n_1(t)$$

$$x_2(t) = \alpha . s(t-d) + n_2(t)$$

where D is the delay between them and α is the attenuation constant. s(t) and s(t-D) are the signal components present in $x_1(t)$ and $x_2(t)$, respectively. $n_1(t)$ and $n_2(t)$ are uncorrelated additive channel noises. It is assumed that $n_1(t)$ and $n_2(t)$ are uncorrelated with s(t).

Correlation between $x_1(t)$ and $x_2(t)$ is

$$\phi_{12}(\tau) = \int_0^T x_1(t)\, x_2(t+\tau)dt$$

where T is the duration of signals $x_1(t)$ and $x_2(t)$.

Assuming that the cross correlation between the signal and the noise sources, the cross correlation between the noise sources are zero, it is seen that, with $\alpha = 1$,

$$\phi_{12}(\tau) = \int_0^t s(t)\, s(t-D)\, dt$$

and this peaks at $\tau = D$, the delay between the two signals.

However in practice the cross correlation between the noise and the signal being not zero, the performance of the correlation is degraded. To reduce the spreading of the peak and to minimize the variance of the estimated delay, suitable weighing w(f) is needed. In fig. 1 the method of estimating the delay using FFT technique is indicated. The problem of selecting w(f) to optimize certain performance criterion has been studied by several investigators (see references) and this has lead to several pre and post processors (See Table 1).

Proposed System

Ambiguity of the position of peak at the output of correlator is due to the presence of random noise in the incoming signal. Presence of tonals in the signal also degrade the performance of the system. It was found that smoothing the cross spectrum improves correlator output. Smoothing can be done either by using cosine bell or running average. But when cosine bell is used we may loose cross spectrum information due to its shape.

The algorithm for smoothing the cross spectrum is explained as follows. Let p_i, $i = 1,2,\ldots, N$ be the N point cross spectrum before averaging and q_i, $i = 1,2,\ldots N$ after m-point running averaging. Here both p and q are complex quantities. The smoothed spectrum after m-point running average is

$$q_i = \sum_{j=i}^{m+i-1} \frac{p_j}{m} \quad ; \; i = 1,2,\ldots N-m+1$$

$$= p_i ; \; i = N-m+2,\ldots N$$

Simulations were conducted for variance m and finally m was chosen as sixteen.

Table 1

Processor	w(f)
Direct correlation	1
SCOT	$\dfrac{1}{(G_{x_1x_1} \; G_{x_2x_2})^{1/2}}$
HB 1	$\dfrac{G_{ss}}{G_{x_1x_1} \; G_{x_2x_2} - a^2 G_{ss}}$
HB2	$\dfrac{G_{ss}}{G_{x_1x_1} \; G_{x_2x_2}}$

$G_{x_1x_2}$ is the cross spectrum of x_1 x_2.

Discussion

All processors were simulated considering 512 samples of corrupted signal. SCOT was also simulated by taking 1024 samples and dividing it into 4 segments having 256 samples or 16 segments having 64 samples. Correlation of the signal and its delayed version was achieved in the frequency domain by FFT. All processors were simulated introducing 5 samples delay (in case of sinusoidal signal case) and 8 samples delay (in case of gaussian signal case).

Thirty four separate simulation experiments were conducted for all the systems at 5dB, 0 dB, -5dB and -10 dB SNR. Simulation results of various processors at these SNR are given in table 2 and table 3. **

Although weighting is intended for improving the system performance, results showed that Direct correlation is better than SCOT. Studies conducted by Scarbrough et al also have reached the same conclusion. HB2 shows better performance than SCOT in case of sinusoidal signals. This result agrees with those of Hassab and Boucher. But HB2 shows poorer performance compared to SCOT with gaussian signals.

Any processor can be improved by segmentation. Simulation of XSCOT was done with a total of 1024 data samples divided into four and sixteen segments. As expected sixteen segments case showed better results than four segments case (Ref. Table 2 and 3).

It was found that Pre-IFFT averaging also improved by segmentation. A signal having 1024 samples was divided into two segments of 512 samples each. The final output was obtained as the point by point average of the two individual outputs after which the peak was selected to yield delay. In case of sinusoidal signal it showed probability success of 0.91 and variance of 2 for -10dB whereas without segmentation they were 0.89 and 2.9 respectively.

**In the simulation study, Pre-IFFT averaging yielded better results as can be seen by Table 2 and 3. The p_s of sinusoidal signal was 90 percent and for gaussian signal was 65 percent.

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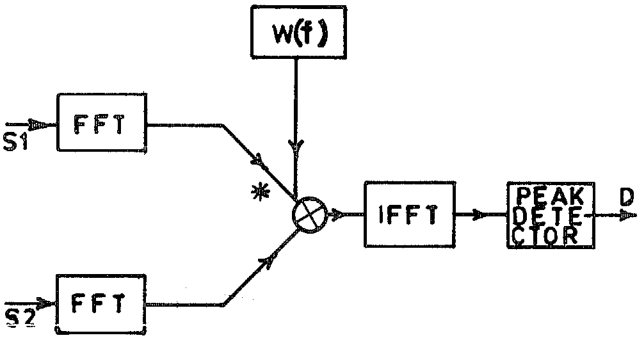

FIG.1

Table : 2 Simulation results of various processors considering corrupted sinusoidal signal as the incoming signals.

SNR	Direct correlation taking 512 samples		SCOT taking 512 samples		SCOT 4 segments each having 256 samples		SCOT 16 segments each having 64 samples		HB1 taking 512 samples		HB2 taking 512 samples		Pre-IFFT average	
	p_s	Va log scale	p_s	Va log scale	p_s	Va log scale	p_s	Va log scale	p_s	Va log scale	p_s	Va log scale	p_s	Va log scale
5dB	.94	1.1778	.3125	3.7992					.156	4.7	.395	4.8138	1	- o0
0dB	.78	2.0271	.25	3.898	.294	3.5	.558	2.79	.156	4.2	.516	4.5953	1	-1.2306
-5dB	.293	3.2259	.1875	4.1013	0.235	3.51	.588	2.2	.125	4.7	.367	4.2329	1	-0.3010
-10dB	.16	3.8345	.156	4.155	0.147	3.585	.323	2.2	.0937	4.7	.27	3.4703	.89	0.4727

Table 3. Simulation results of various processors considering corrupted gaussian signal as the incoming signals

SNR	Direct correlation taking 512 samples		SCOT taking 512 samples		SOCT 4 segments each having 256 samples		SCOT 16 segments each having 64 samples		HB2 taking 512 samples		Pre IFFT average	
	p_s	Va log scale	p_s	Va log scale	p_s	Va log scale	p_s	V_a log scale	p_s	Va log scale	p_s	Va log scale
5dB	1	- o0	1	-0.6864					0.05	4.895	1	- o0
0dB	1	-0.7533	1	-0.4901	1	-0.628	1	-0.6172	0.03	4.773	1	-0.8324
-5dB	1	-0.4175	0.94	2.2025	.9705	-0.02632	1	-0.1836	0.05	4.6107	1	-0.2763
-10dB	0.55	3.4327	0.34	3.9760	.705	3.1986	.724	0.637	0	4.6818	.65	1.2574