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AN INTEGRATED APPROACH TO SIGNAL AND IMAGE PROCESSING FOR OCEAN--ETC(U)
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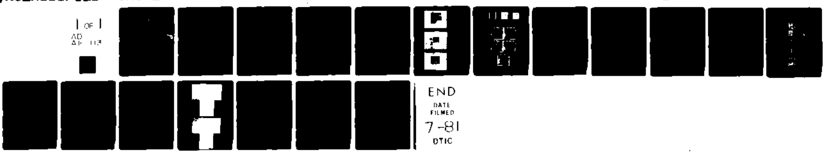

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AN INTEGRATED APPROACH TO SIGNAL AND IMAGE PROCESSING FOR OCEAN ACOUSTICS*

(11) 29 Jun 81

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AN INTEGRATED APPROACH TO SIGNAL AND IMAGE PROCESSING FOR OCEAN ACOUSTICS

I. Introduction

Many sophisticated algorithms have now been developed to process the ocean acoustic data gathered by various sensors. However, many efforts are disjoint and fragmented. Computational requirements usually are not considered. Algorithms that require many hours of computation are not suitable for ocean surveillance. To meet the overall system's requirements, trade-off between accuracy and speed (or computational requirements) is much needed. Furthermore informations from various sources must be jointly utilized or properly integrated for effective processing. The two-dimensional presentation of the multidimensional signal is most desirable. The ambiguity surface function is the most typical images studied in ocean acoustics. The waveform data can be processed in two dimensions by considering space-time and spectrum-time relations. The three-dimensional ocean environment may be reconstructed from the two-dimensional images.

Experiences have shown that the use of one algorithm alone is not adequate and that several algorithms are often needed for a given task.

For the given ocean surveillance requirements, the proposed integrated approach is a system's approach that utilizes a command processor to coordinate the following functions performed by the individual processors.

1. Space-time and space-space spectral analysis of the transient signals. This requires high speed and high resolution

spectral analysis capability.

2. Adaptive filtering and detection of the transient signals in non-Gaussian background noise. This requires noise self-cancelling capability to remove the unwanted noise for a rapid detection of the presence of the desired signals.

3. The parameter extraction from the array processors. The updated range, the rage rate and even the acceleration information should be used by the command processor in its interpretation and decision making about the real environment such as the presence of a submarine.

4. The statistical image segmentation and feature extraction of imagery data. The statistical pattern recognition techniques can provide effective image segmentation and feature extraction necessary for classification and interpretation of the objects or targets from a cluttered background.

5. Effective image enhancement and display for the man-machine interface.

6. The three-dimensional reconstruction and display of the moving objects (targets). This task requires considerable amount of computation and will be performed if directed by the command processor.

Briefly the command processor coordinates all signal processors, and integrates informations from various processors for the intelligent decision making or interpretation. At the present stage of development, the command processor represents a conceptual design of a signal and image processing system for the ocean acoustics. In this report we shall examine several processing functions and describe our efforts to implement the approach.

II. Statistical Image Segmentation Via Pixel Classification

Image segmentation is a partition of an image into several meaningful parts. The statistical segmentation is based on the assumption that pixels belonging to the same part tend to have the same statistical properties. By classifying each pixel, a complete image can be segmented. For pictures with very complicated scenes, the statistical segmentation is not feasible as the number of pattern classes is large and the statistical samples for some classes may be inadequate. For the remotely sensed imagery that includes primarily the object and the background in a scene, and for the acoustic ambiguity surface in which the estimation of doppler-delay from the noisy data is made, the statistical segmentation techniques are most effective. The desired object can be extracted from the background by segmentation. If pixels of a known classification are available, we have the supervised segmentation. The supervised segmentation generally performs better than the unsupervised segmentation which does not use the information of classified pixels. Although statistical segmentation can be performed by a direct boundary estimation, pixel classification is more simple and efficient.

The four classification techniques we have examined (Refs.1 - 4) are the Fisher's linear discriminant, maximum likelihood region estimation, maximum a posteriori region estimation, and the iterative

Bayes classification. For the remotely sensed images such as the infrared and reconnaissance (aerial photographic) images, the Fisher's linear discriminant performs very well. For the textured images, the iterative Bayes classification is most effective with the properly selected textured features that include the angular second moment, contrast (or moment of inertia), correlation, and third moment. However, extensive computation is required to calculate the co-occurrence matrix needed to compute the textured features. For the textured image as shown in Fig. 1, the following is a list of segmentation errors based on the classification results.

(a) Fisher's linear discriminant
4.6% with neighboring pixels as features
2.05% with textured features

(b) Maximum likelihood estimation: about 10%

(c) Maximum a posteriori estimation: 3.96%

(d) Iterative Bayes classification
1.56% with textured features

In both (b) and (c), the features are neighboring pixels which are represented by first order autoregressive models. Detailed procedures are available in Refs. 5 and 6.

For the unsupervised segmentation, the decision-directed method using the conditional population mixture model is not effective from our experimental study. The ARMA modelling which is unsupervised, however, can be useful for the textured image segmentation. For a slight variation of the textured image in Fig. 1b, the new image Fig. 2a is used for the object-extraction

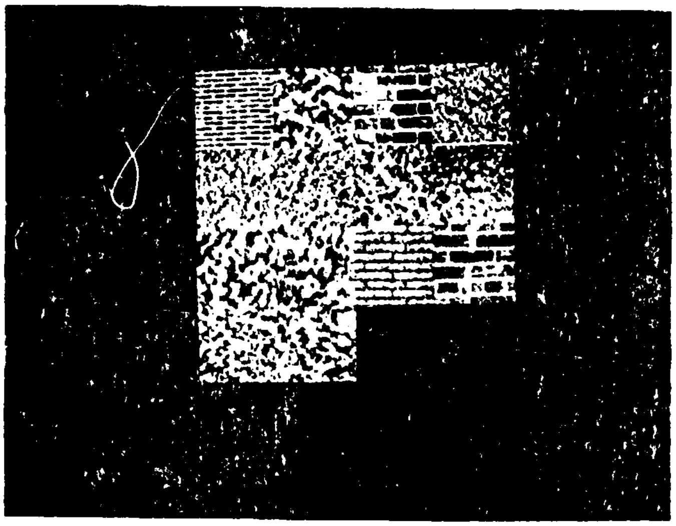

Fig. 1 A set of textured images from USC image data base, #B2368-38

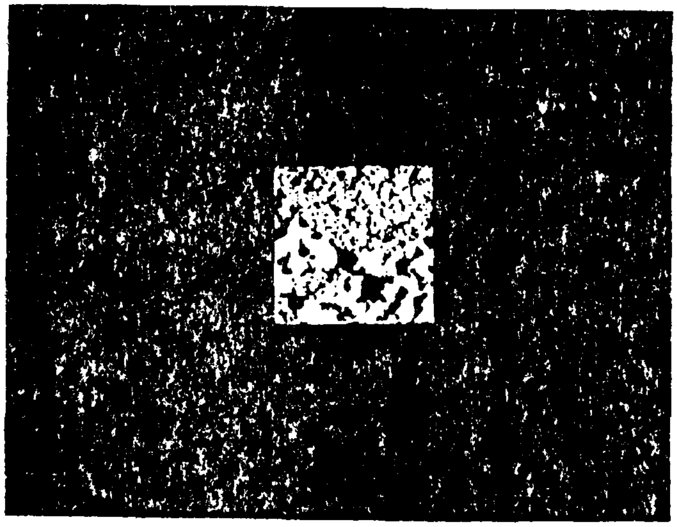

Fig. 1a First zooming of a constructed textured image.

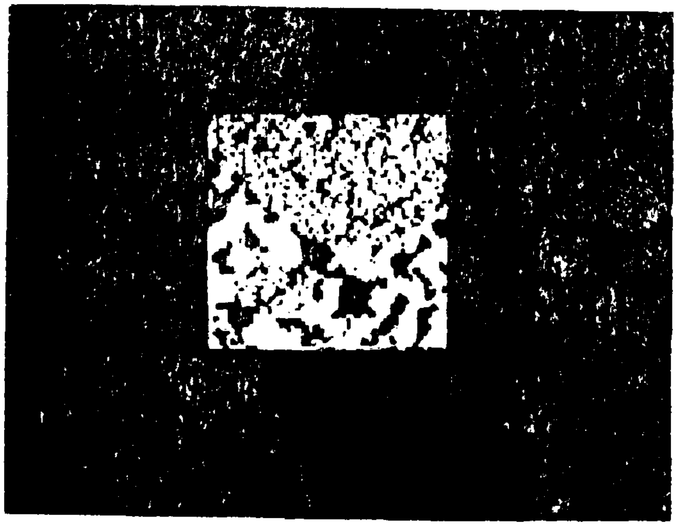

Fig. 1b Second zooming of the image shown in Fig. 1a.

Fig. 2a

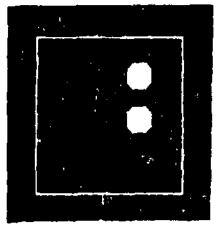

Fig. 2b

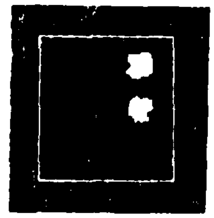

Fig. 2c

Fig. 3a
(note: noise
s.d. = 0.14)

Fig. 3b

Fig. 3c

Fig. 3d

Fig. 3e

experiment. The ARMA modelling procedure [7] can segment the image to extract the textured object with only 1.68% error.

In summary, the statistical image segmentation should be very effective for the ocean acoustic imagery in surveillance and tracking applications. Segmentation of the acoustic ambiguity surface images remains to be studied.

III. Statistical Image Filtering

Additive/multiplicative noises and measurement errors are almost always present in the ocean acoustic images. Each type of noise requires a specific class of filtering techniques. For the additive noises, Kalman filtering is among the most effective techniques. The multiplicative noise, due particularly to the signal dependent film-grain noise, can be significant in radar imagery such as the Seasat images. The use of local statistics is quite efficient in removing both additive and multiplicative noises (Refs. 8 and 9). The adaptive digital filtering has also been used for the removal of the multiplicative noise [10]. In all work of the statistical image filtering, edges and boundaries should be preserved as the filtering operation tends to blur the edge or boundary. The use of a single algorithm thus may not be adequate. Post-processing may be necessary following the filtering operation. Furthermore, techniques are often application dependent.

For the ocean acoustic imagery, we recommend Kalman filtering for the removal of the additive noise and the use of local statistics as well as the adaptive digital filtering to remove the multiplicative noise. Fig. 3a is a Seasat image of Santa Barbara area. There is a significant amount of granular noise and the use of local statistics can greatly remove such multiplicative noise as shown in Fig. 3b (with the courtesy of Dr. Jong-Sen Lee of Naval Research Lab.). Horizontal processing (Fig. 3c) and horizontal-followed-by-vertical processing (Fig. 3d) by using Kalman filtering improve the contrast but keep the granular noise almost intact. Fig. 3e is the result of adaptive noise cancelling. Such adaptive filtering based on 5x5 windows is as effective as the use of local statistics. The adaptive digital filtering employed here follows the same procedure as we used for the seismic signal processing [11].

IV. Time-Delay Estimation

The problem of time-delay estimation is of fundamental importance in sonar signal processing and has been well studied [12] [13]. Recently, two optimal filters (windows) for time-delay estimation were developed by J.C. Hassab [14] by using the criterion of maximization of the expected signal peak relative to the output noise of a generalized correlator. The resulting performance is shown to be superior to several other filter-estimators. In this report, a different approach to the time-delay estimation is presented, which has never been published before. The approach uses a program of the multi-channel maximum entropy spectral analysis, which we developed earlier [15] to determine the coherence between the two channels of data. The phase difference at peak coherence value is used to compute the time delay. The two received signals considered are

$$z_1(t) = y(t) + n_1(t)$$

$$z_2(t) = ay(t-D) + n_2(t); \qquad a=0.9$$

where D is the delay, a is attenuation, and $n_1(t)$ and $n_2(t)$ are uncorrelated noises. Several experimental results are reported as follows. Assume D=10 units.

When y(t) is a complex sinusoid, the percentage error of the estimate as a function of signal-to-noise ratio is shown in Fig. 4a. By using the imaginary part only of the received signal, the percentage error curve is shown in Fig. 4b. At signal-to-noise of 20 dB or above, the estimation error is almost negligible.

When y(t) is a random signal with a second order spectra as shown in Fig. 5a (linear plot) and Fig. 5b (log plot), and the noises are Gaussian, the phase difference and coherence function are shown in Fig. 5c and the histogram of the time-delay estimate is shown in Fig. 5d. In this case, the delay corresponds to the peak value of the histogram at which point the delay is accurately determined as 10 units, for a signal-to-noise ratio of 20 dB.

When y(t) consists of both a random signal and a sinusoid, and the noise is Gaussian, a power ratio can be defined as the ratio of the variance of the random signal to the power of the sinusoid. The variance is fixed at 1. The peak coherence value instead of the histogram is more suitable to determine the time delay estimate in this case. Fig. 6a is a plot of percentage error as a function of power ratio. Fig. 6b is a plot of the

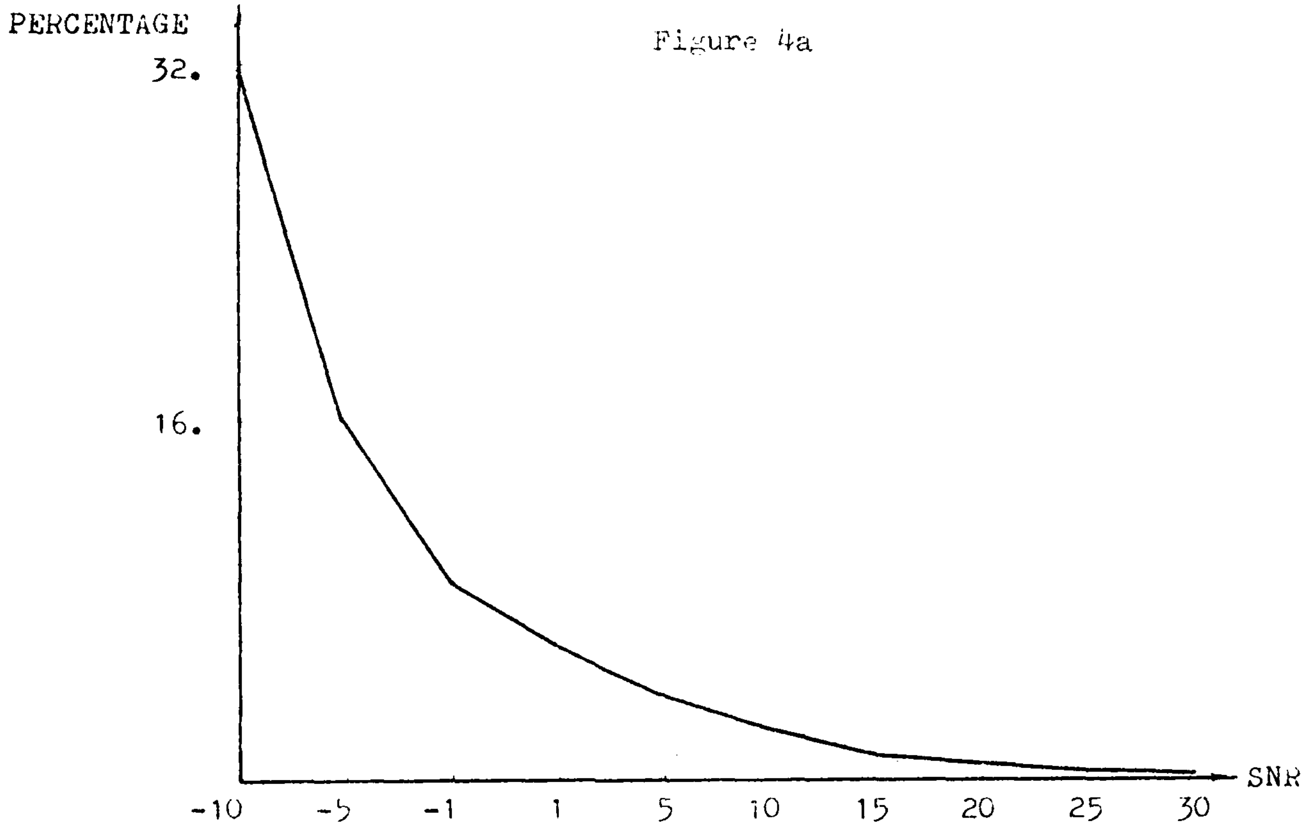
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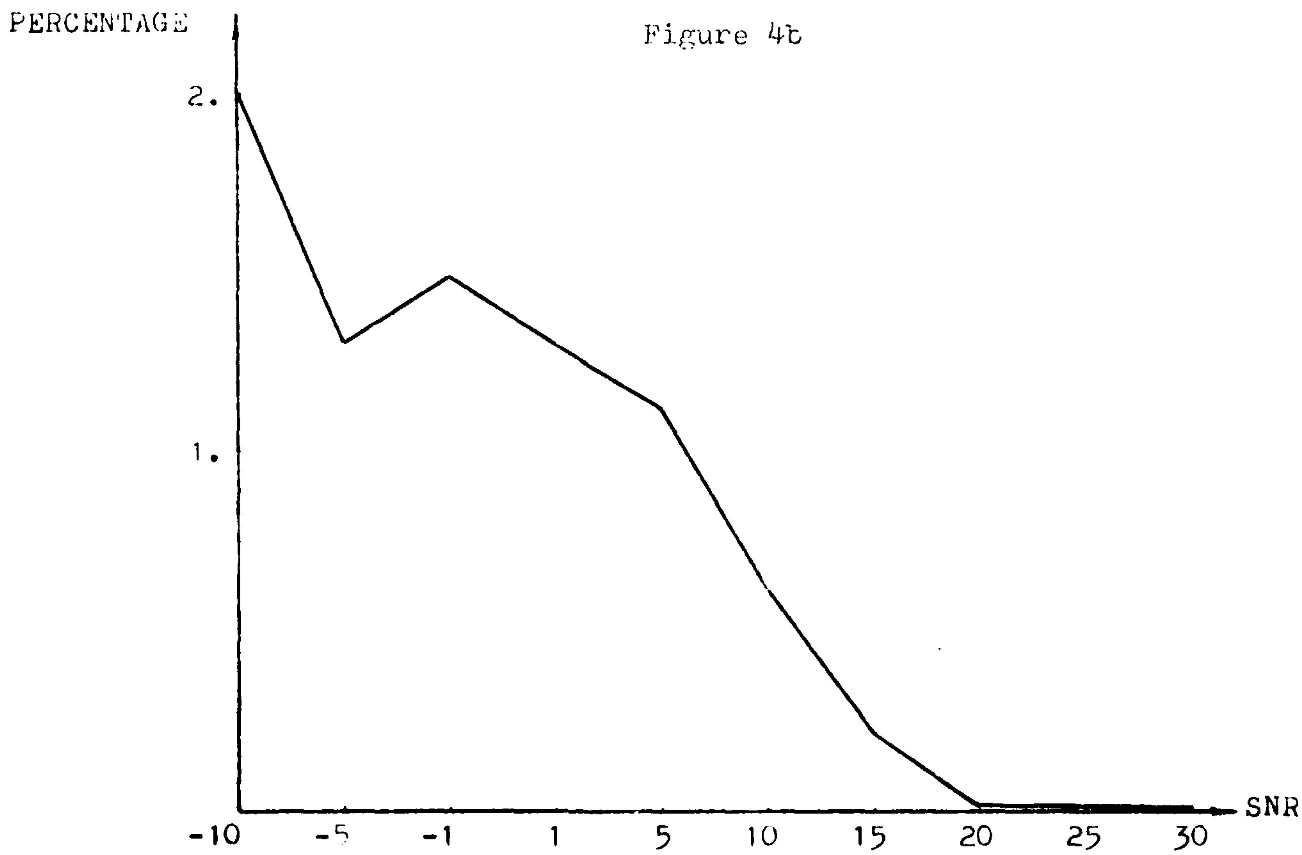
Figure 4a
32.
16.
-10
-5
-1
1
5
10
15
20
25
30
SNR


PERCENTAGE
Figure 4b
2.
1.
-10
-5
-1
1
5
10
15
20
25
30
SNR

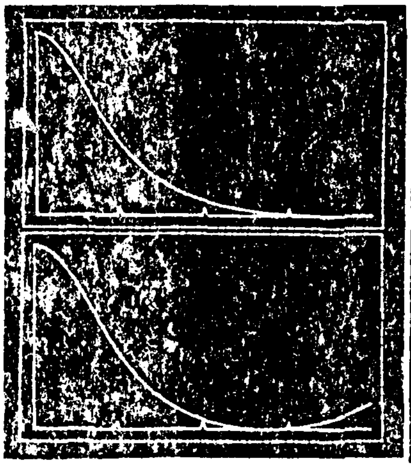


Fig. 5a

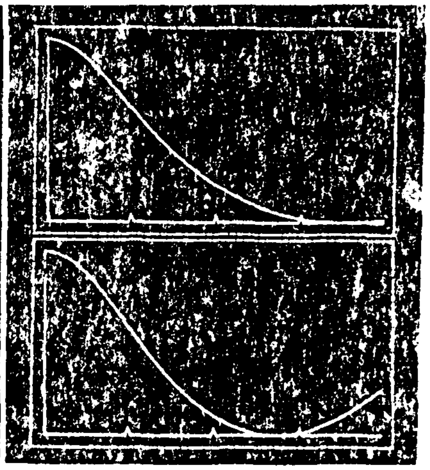


Fig. 5b

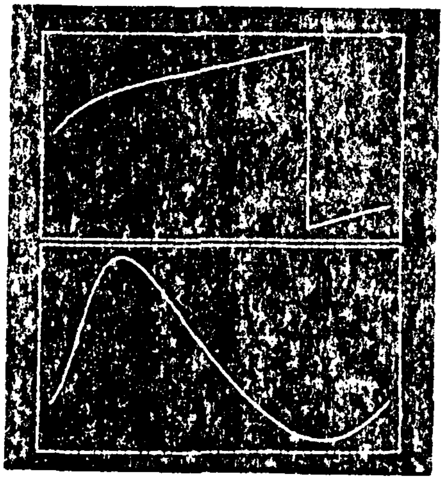


Fig. 5c
phase difference(upper)
coherence(lower

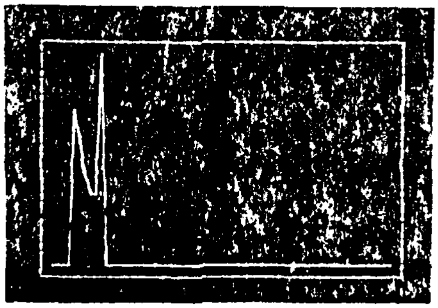


Fig. 5d
peak value occurs at
exactly 10 units of time.

Figure 6a

POWER RATIO	$\hat{\tau}$	ERROR PERCENTAGE (%)
0.1	8.77658	12.2341
0.2	9.11405	8.8602
0.3	9.28085	7.1922
0.4	9.38474	6.1526
0.5	9.45708	5.4292
1	9.63810	3.6191
2	9.76146	2.3854
3	9.81269	1.8731
4	9.84180	1.5820
5	9.86099	1.3902
10	9.90618	0.9384
15	9.92511	0.7492
20	9.93609	0.6392
25	9.94345	0.5663
50	9.96119	0.3884
100	9.97324	0.2681

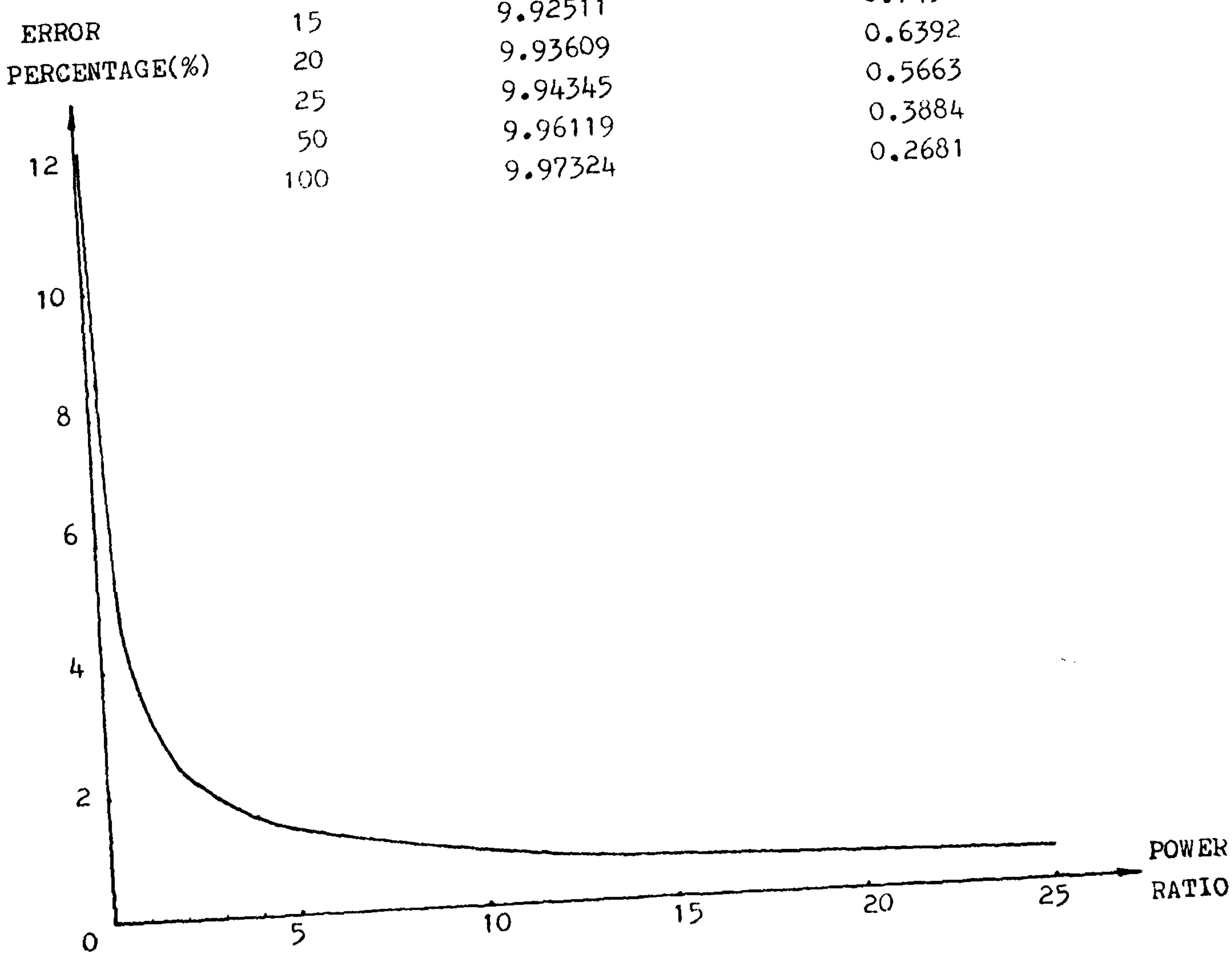
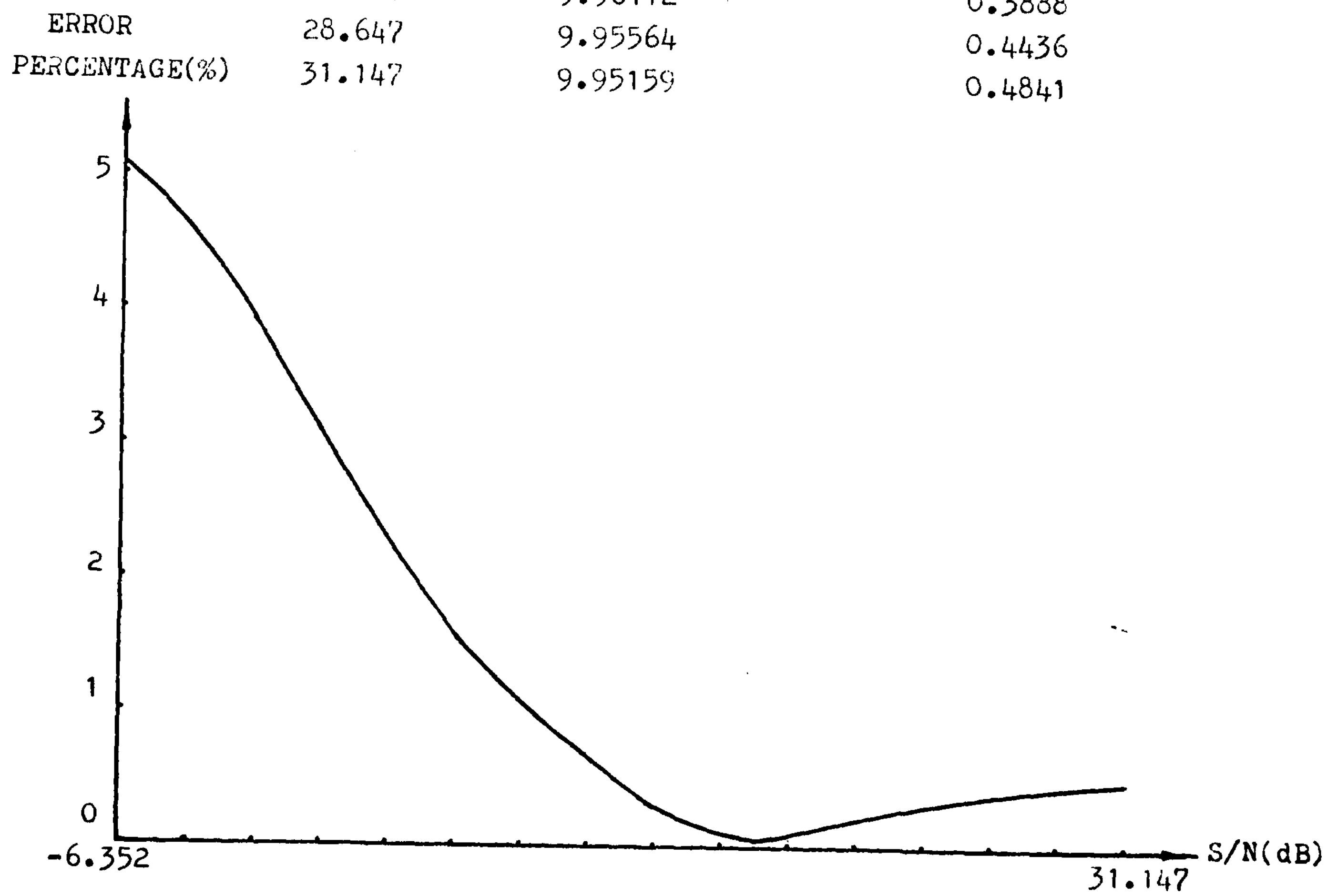


Figure 6b

S/N	$\hat{\tau}$	ERROR PERCENTAGE(%)
-6.352	10.50214	5.0214
-3.852	10.46055	4.6055
-1.352	10.38919	3.8919
1.147	10.30748	3.0748
3.647	10.22917	2.2917
6.147	10.16171	1.6171
8.647	10.10735	1.0735
11.147	10.06528	0.6528
13.647	10.03345	0.3345
16.147	10.00960	0.0960
18.147	9.99494	0.0506
18.647	9.99178	0.0822
20.147	9.98331	0.1669
22.147	9.97411	0.2589
23.647	9.96850	0.3150
26.147	9.96112	0.3888
28.647	9.95564	0.4436
31.147	9.95159	0.4841



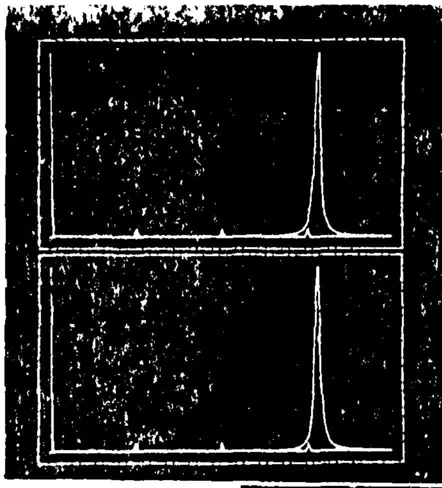
percentage error versus the signal-to-noise ratio at the power ratio of 1/25. Again a reasonably accurate estimate of time delay can be determined. For a power ratio of 1/25, Fig. 7 has the spectral plots in linear scale (a) and in log scale (b) and the phase difference and coherence function in upper and lower parts of Fig. 7c respectively. Similarly, for a power ratio of 1 and the signal-to-noise ratio of 29 dB, the corresponding plots are given by Figs. 8a, 8b and 8c.

The time delay estimation discussed in this section is a good example of the integrated approach in which the high resolution spectral analysis method is applied to the parameter estimation problem. The resulting performance is very comparable with the conventional filter-correlator approach which is computationally much more demanding.

V. Comments on the Command Processor

The integrated system is equipped with the basic tools such as the high resolution spectral analysis, the image segmentation and enhancement algorithms, etc. The command processor must first decide for a given task what tool or tools to be used. The information extracted must be evaluated to determine its reliability by using a priori knowledge available. Then the information is interpretated with the aid of a dicision table. If necessary further processing can be requested by the command processor. Because of the cost involved, most systems now use only one algorithm to extract one set of information. The integrated

Fig. 7a



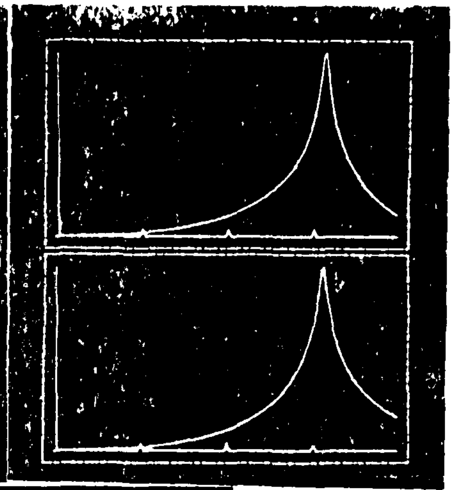


Fig. 7b

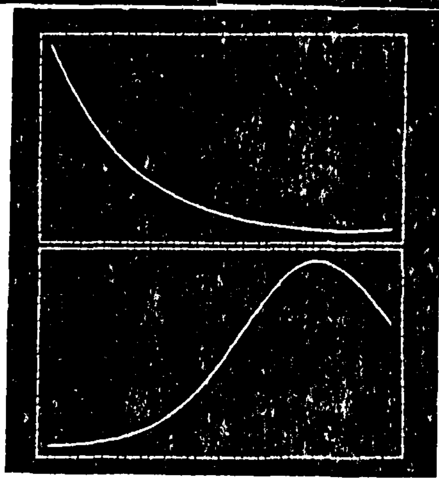
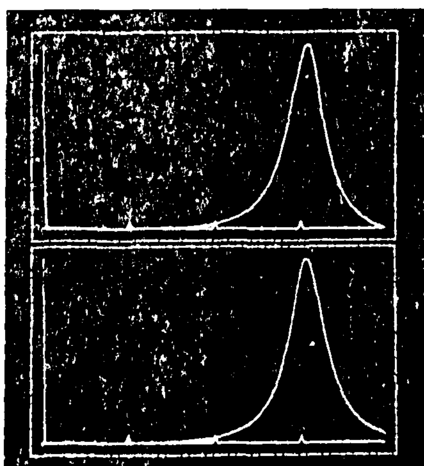


Fig. 7c

Fig. 8a



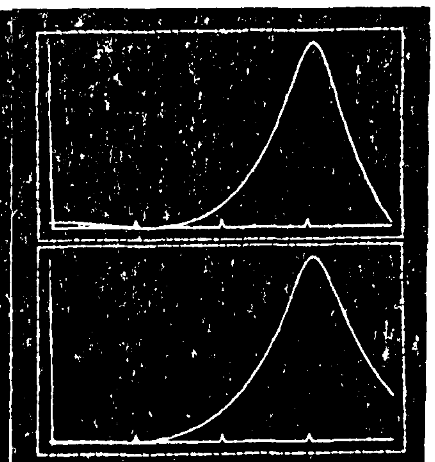


Fig. 8b

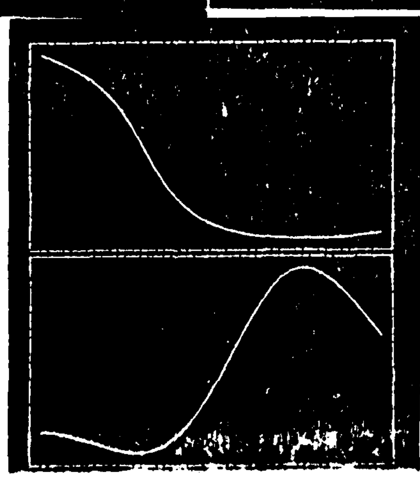


Fig. 8c

system should be utilized for more difficult signal processing tasks.

Our on-going effort to develop the integrated approach has resulted in a complete system that performs both signal and image processing as well as pattern recognition and detection/ estimation. Further efforts will be devoted to the command (or intelligent) processor and to the enhanced capability of individual processors.

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Integrated approach, space-time processing, image enhancement; image segmentation; statistical segmentation techniques; time-delay estimation; multichannel maximum entropy spectral analysis; statistical image filtering; command processor; intelligent systems.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An integrated systems approach is presented that includes both signal and image processing capability, and the use of command processor to coordinate the operation of all processors, and to make intelligent interpretation of real environment and to extract desired information from noisy background. Both statistical image segmentation and time-delay estimation are examined in this context.

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