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Time-Frequency Methods for Detection and Classification of Long Buried Targets

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This paper presents the development and evaluation of time-frequency processing techniques for detection and classification of buried targets from parametric sonar data. The software is designed to discriminate between various target types. Of particular interest are long targets such as cables of various diameters, which need to be identified as different from other strong reflectors or point targets. The targets of interest are buried a few meters deep in the ocean sediment.

The sonar in question is the Parametric Detection and Imaging Sensor (PARADISE), designed and developed by the Naval Research Laboratory. This sonar consists of three parametric hydrophones simultaneously pinging at high speed, imposing tough requirements on real-time processing capabilities.

An overview of the processing system is shown in Fig. 1. If signals from the three hydrophones are available, a coherence detector is used to provide a first level of classification that indicates whether the target is present in all and therefore, most probably, a cable-like target. The fractional Fourier transform of optimum order is estimated based on the properties of the transmitted signal and used to obtain the impulse response of the targets through a novel deconvolution method. Time-frequency methods are then applied to obtain the energy distribution of the target simultaneously in time and frequency, through the Wigner or the Choi-Williams distributions.

Features are extracted from the time-domain returns and from the time-frequency distributions of the bottom impulse response. The latter features are derived from the singular values of the distributions. An example using the Choi-Williams distribution of simulated returns when a cable is present is shown in Fig. 2. Hough transforms are used to detect lines and characterize the targets found as shown in Fig. 3.

Principal Component analysis is then used to reduce the dimensionality of the combined feature space by removing correlation among features and discarding those components which contribute the least to the overall variance.

Discriminant analysis, a widely used statistical pattern classification technique which maximizes the ratio of the overall scatter to the within-class scatter is used to classify the targets (long, point) and separate them from reverberation. The functions are derived from Bayes's rule with equal cost for wrong decisions. The final discriminant score incorporates the Mahalanobis distance (and therefore the covariance matrix) between the transformed measurements and the class prototype as the determining factor in the classification.

Synthetic and actual test data are used to exemplify and evaluate the techniques. Results are presented that illustrate the processing procedure and show that these algorithms provide accurate ways to detect and classify buried objects with high probability of correct classification and low false alarm rates.

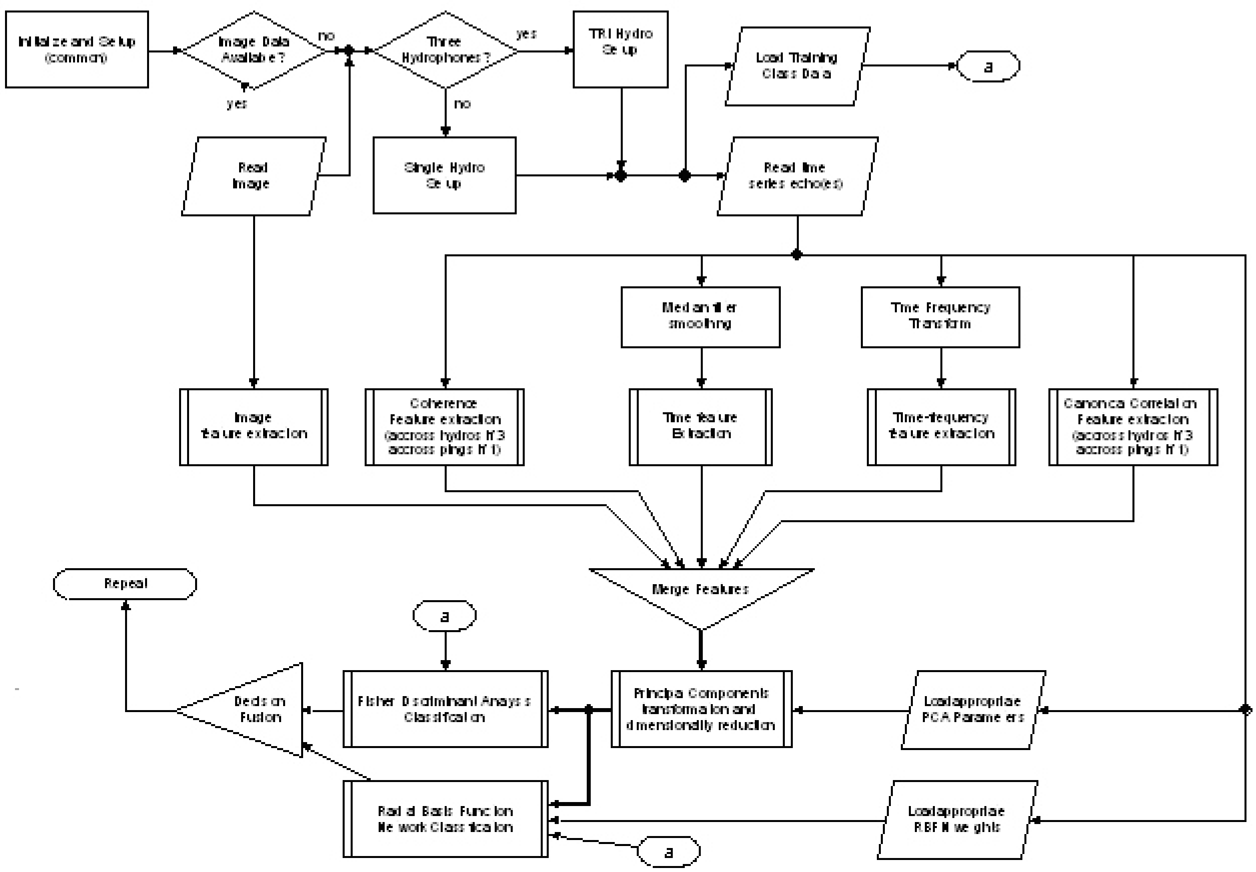

Fig. 1: Flow diagram of detection and classification process for PARADISE.

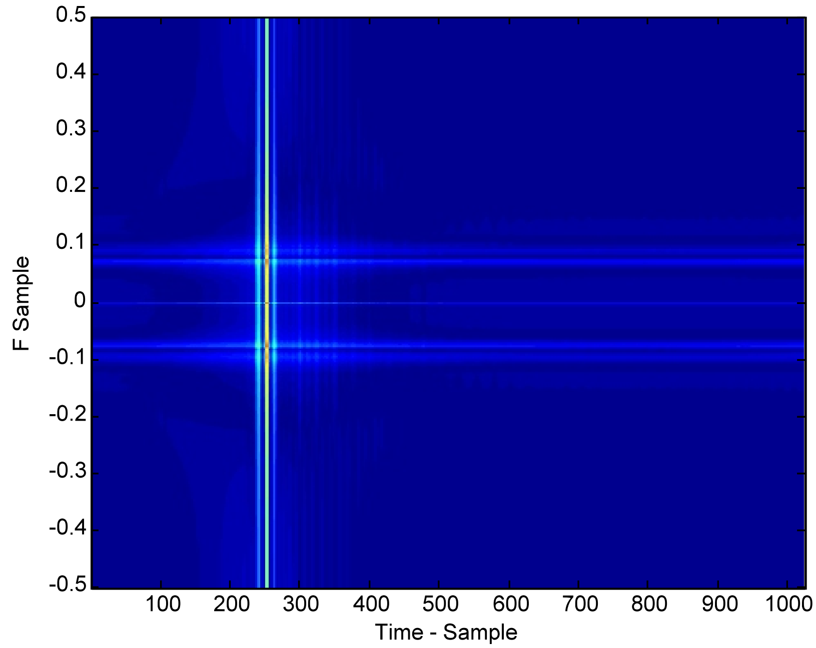

Figure 2: Choi-Williams distribution with cable target present.

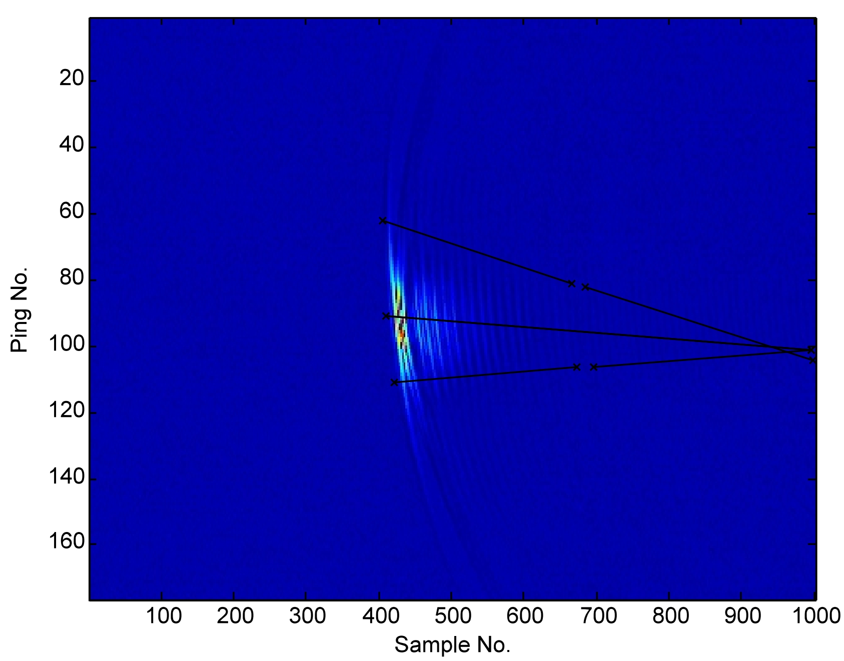

Figure 3: Hough line detection used to characterize cable targets.