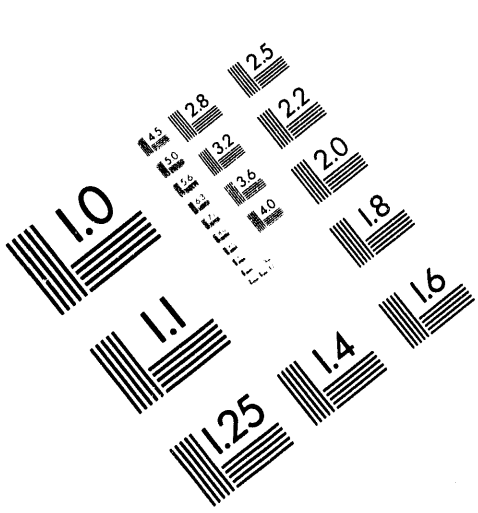

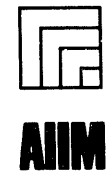

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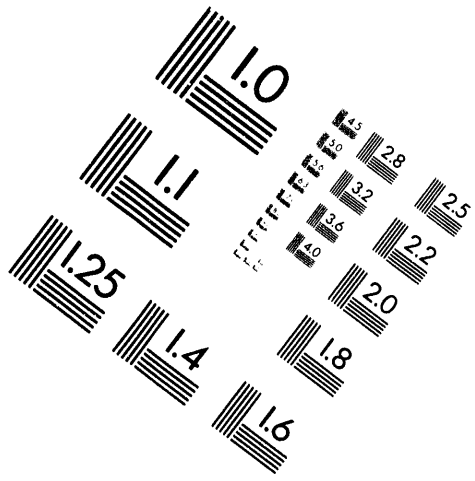

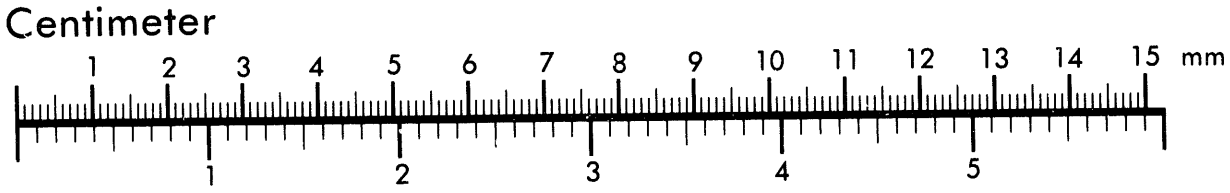

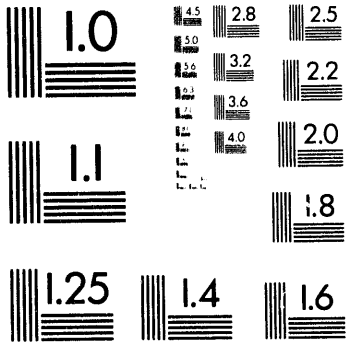

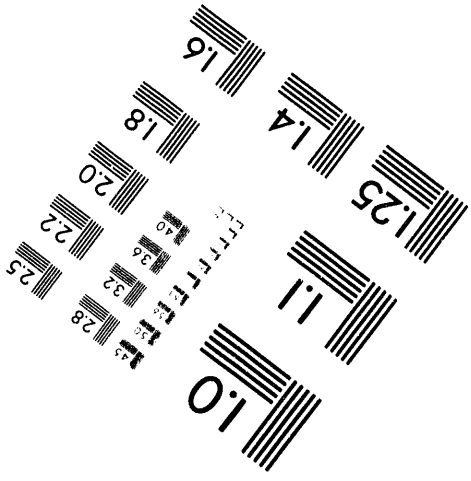

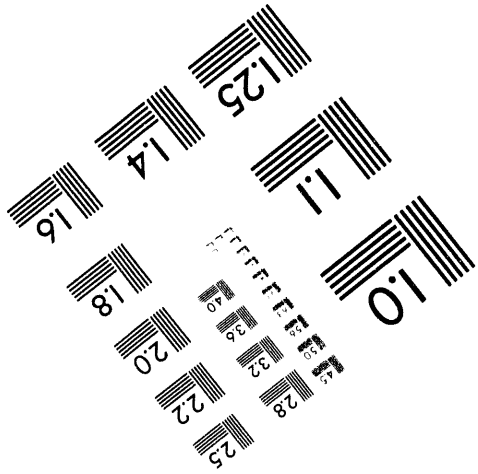

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AN APPLICATION OF WAVELET TRANSFORM FOR DECOMPOSITION OF MILLIMETER-WAVE SPECTROSCOPIC SIGNALS*

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An Application of Wavelet Transform for Decomposition of Millimeter-Wave Spectroscopic Signals

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Abstract

Millimeter-wave technique, based on rotational energy transitions of molecules, holds promise for remote monitoring of environmentally hazardous effluents from processes. Argonne National Laboratory is developing a millimeter-wave sensor based on active swept-frequency radar technique in the frequency range of 220-320 GHz. Because the line widths of millimeter-wave spectra of molecules at atmospheric pressure are broad (~ 4 GHz half-width at half height), the composite spectrum of multicomponent mixtures of chemicals is generally complex and overlapping. This paper presents an application of discrete wavelet transform for efficient representation and decomposition of millimeter-wave spectral data. A two-layer back propagation neural network is trained using multifrequency wavelet coefficients of the signals as input features and the known

composition of different chemicals in the mixture as target output vectors. After training, composition of an unknown mixture of the base chemicals is determined using the wavelet representation of its absorption spectra. Simulated and experimental spectral data were used to test the wavelet transform technique. Accurate values of individual chemical compositions resulted for noise-free laboratory data. In addition, the technique showed more robustness than conventional multivariate techniques under noisy conditions.

Introduction

Because millimeter (mm) waves offer better transmission properties than optics in cloudy and dusty environments, spectroscopic techniques using mm waves are considered for remote monitoring of airborne effluents [1]. The technique consists of transmitting a swept-frequency electromagnetic signal in the range of 220 to 320 GHz into a chemical plume and receiving the radiation from a corner reflector (or ground terrain) in a monostatic configuration. The mm-wave signal received after absorption by the plume over a two-way path contains the composite spectra of the chemicals in the plume. At low pressures (below about 1 Torr), the spectral lines of molecules are generally sharp and far apart so that they form well-defined and unique signatures for many chemicals of interest. At atmospheric pressure, however, pressure-induced molecular collisions cause broadening of the absorption spectra. This broadening effect renders the detection of target chemicals in a mixture of chemicals difficult due to (a) self-broadening and merging

of closely spaced spectral lines and (b) overlapping of neighboring spectra from other chemicals. The effect of pressure broadening on chemical resolvability may be circumvented to a large extent by using a high-frequency mm-wave system with wide sweep capability (a basis for selection of 220-320 GHz system) and by multivariate analysis. This paper applies wavelet transforms in conjunction with a neural net for decomposition of mm-wave spectra.

Discrete Wavelet Transform

Multifrequency wavelet transform W(s,d) (the discrete wavelet transform - DWT) of a discretized signal x(k) on a dyadic grid in the time-scale plane is defined by [2]

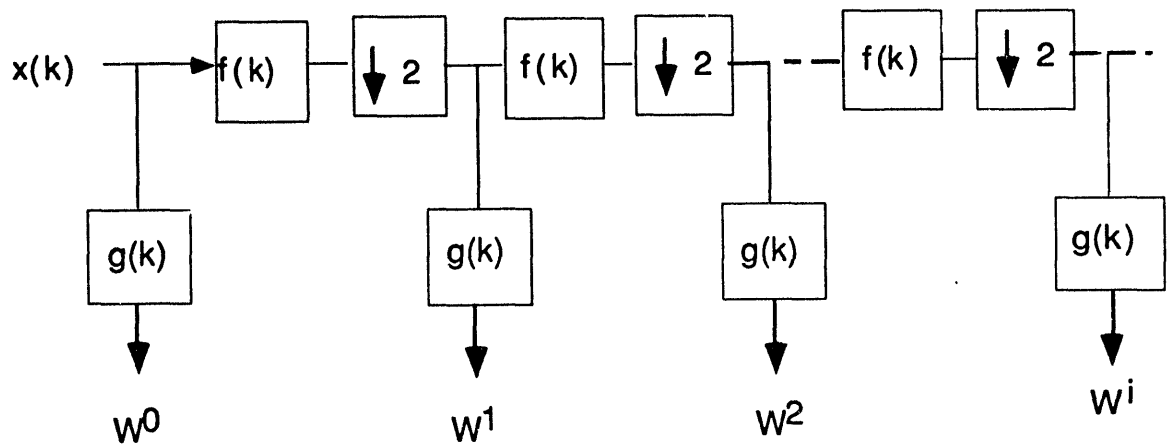
$$W(s,d) = W(2^i, 2^i n) = W^i = (1/\sqrt{2^i}) \sum_k g^*[(k/2^i) - n] x(k) \qquad (1)$$

where g(t) is the mother wavelet corresponding to s = 1 and d = 0. The power-of-two values for the scale, $s = 2^i$, and the integral values for the time, $d = 2^i n$, i,n = 0, 1, ..., enable efficient implementation of the above equation using an interpolation (a trous) filter and decimation by 2 [3]. Fig. 1 shows the filter bank structure used to implement Eq. (1).

In the initial evaluation of the method, Morlet mother wavelet, defined by

$$g(t) = e^{jwt}e^{-Kt^2} \qquad (2)$$

is used to obtain nonorthogonal wavelets at scales $s = 2^i$. Undecimated wavelet coefficients are obtained for three octaves (i = 0,1,2 and 3).



f(k) : Interpolation Filter g(k) : Mother Wavelet

x(k) : Input Samples Wi : Wavelet Coefficients

Fig. 1 Filter bank structure for implementing Eq. (1)

Signal Decomposition

The proposed decomposition method was initially applied to a mixture of three chemicals, C_1, C_2, and C_3. Experimental spectroscopic data for each of three chemicals at known

concentrations (partial pressures) were obtained in the frquency range of 220-320 GHz. Nine data sets, s_k, k = 1, 2, .. 9 corresponding to synthesized mixtures of the three chemicals at concentrations c_{1k}, c_{2k} and c_{3k} were created by linear combination of the three measured spectroscopic data. These nine sets with their concentrations formed the reference set. DWT coefficients, $W_k(2^i,2^in)$ for the reference set of data were used as features characterizing the data.

A two-layer back propagation neural network was trained using the wavelet domain features. The trained network was tested with synthesized and experimental compositions of data. Resulting concentrations were within 0.2 % of the actual values for synthesized data and within 1 % for experimental data. To simulate the presence of nontargeted chemicals in the experimental spectral data and also instrumentation noise, white noise with about 10 % power level was added to the unknown composite data. Initial results in concentrations for synthesized and experimental data were within 0.5 % of actual values. With noise added, the network yielded concentrations within 1 %. While results of partial least squares analysis [4] were in excellent agreement with actual values for noise-free data, they were in error for the cases with noise.

Conclusion

An application of wavelet transform as a preprocessor for decomposition of spectroscopic signals has been described. Results

based on the representation of signals using three octaves of frequency in the Morlet wavelet indicate the method is a viable alternative to conventional decomposition techniques. Efficiency of representation using smaller number of frequency octaves and decimated wavelet coefficients is presently under investigation.

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Subcategory : First Choice: 8.6 Pattern recognition and applications

Second Choice: 8.9 Application of wavelets

Problem: The problem addresses a method of determining the concentration of different molecules in a plume of chemicals from millimeter wave absorption spectrum. A pattern of spectra with known concentrations of the chemicals to be determined are used to train a neural network. Wavelet transform coeffcients form efficient

feature vectors for each chemical. The problem is important because (a) the large size of spectroscopic data warrants long periods of training for the neural network with large number of training sets, and (b) noise in the field measurement of unknown plumes makes the decomposition difficult using conventional multivariate analysis techniques.

Original contribution: The original contribution of this paper is the application of wavelet transform as a feature extractor for nonstationary spectroscopic signals. Decomposition of chemical concentration using the wavelet coefficients shows better results than multivariate analysis, particularly under noisy conditions. The present work applies the work cited in [2].

Other submissions by the authors: None

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