MULTICHANNEL DISTANCE FILTERING OF SEISMIC ELECTRIC SIGNALS

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ABSTRACT

A novel type of distance weighted multichannel filter is used to filter correlated multichannel 1-D seismic electric signals. These signals are weak, short time variations of the geoelectric field occurring prior to an earthquake. The new filters use intersample distances to compute coefficients. Both vector and componentwise correlation is utilised in the computation. The new composite distance filters preserve better, sharp edges and correlated signal features while at the same time possess very good noise suppression properties.

I INTRODUCTION

The use of order statistics (OS) filters has been extended to the correlated multichannel case. Most works examine the general problem of multivariate ordering and focus in color image filtering applications [1,2]. Processing of multivariate data is stongly based on sample distances and recently, a new class of filters have been introduced for the single and multichannel case, applying variable, adaptive to the signal, distance dependent weighting coefficients [3,4]. In the present work a new version of the distance filters is proposed and tested with multichannel correlated geophysical data.

Over the years, unusual variations of several physical parameters, occurring prior to an earthquake, have being examined and much effort has been put to correlate these with the impeding earthquake. The development of earthquake prediction methods proceeds from the assumption that some variations of geophysical and geochemical fields occur before strong earthquakes due to the accumulation of geotectonic stresses in the focal region. Among other methods aiming at short term earthquake prediction , prediction based on the so called seismic electric signals (SES) seems very promising. These are pulse like signals embedded within the electroteluric field. Noise presence obscures signal details and prevents accurate and robust estimation of signal parameters that are useful in the prediction process. It can be considered as a single source multiple receiver problem. Receiving stations are located at different cites around the epicentral area and data of interest are expected to be correlated.

II THE NATURE OF SEISMIC ELECTRIC SIGNALS

Recordings of anomalous changes of the natural electric field of the earth in search of precursors of strong earthquakes, have been reported by many researchers. In Greece, a systematic observation of the Earth's electric field transients as earthquake precursors has been conducted since 1981 by the VAN network of stations and a great amount of data have been collected [5].

Seismic electric signal generation is based on the theory of piezo-stimulated current and originate from the earthquakes epicentral region. The earthquake is expected to occur within several weeks of the appearance of the SES. The electric field at each station is usually monitored in two directions (N-S and E-W) by an appropriate number of electrode pairs. Signal amplitude levels and polarities in the two directions as well as the station's spatial location can be related to the magnitude and focal region of the impeding earthquake .

SES amplitude is among others considered to be proportional to a) the earthquake magnitude M, b) distance r of the station from the epicentral region , obeying an analogous to 1/r law , d) cite and signal propagation path characteristics , e) the electrode spacing, obeying a ÄV/L=constant characteristic, where ÄV is the potential difference and L the electrode spacing. Different electrode separation distance is used. This can vary from 50 meters to some kilometres. Finally, station sensitivity seems also to be a key issue.

Although SES signals have very often different shapes, these are usually identified by the abrupt and strongly correlated among the different channels, variations in the intensity of the monitored electric field. Experimental laboratory observation of, transient electric signals prior to rock failure under uniaxial compression, also demonstrate the pulse like shape of these signals [7]. It is possible that the observed SES is the envelope of a more complex waveform modified by path, site and instrument characteristics.

Seismic electric signals are of relatively low voltage, in the mvolt range and have usually a time duration from a few minutes to hours . These signals are often embedded in noise. White thermal noise, local electrical industrial noise, electrical spikes and noise due to variations of the earth's magnetic field , are among the most common causes. Depending on the number of operating stations at the time and electrode pairs present, a series of multichannel 1-D signals is available for processing. In the following sections the problem will be modelled and a new nonlinear algorithm, appropriate for noise smoothing of these data sequences, will be presented.

III THE NEW FILTER

In the general case the p-channel one dimensional signal is given by

$$X(n) = [X_1(n), X_2(n), \dots, X_p(n)]^T \qquad (1)$$

where each $X_i(n)$ is an 1-D random sequence and n is a sample or time indicator.

When there is no signal present, noise among channels is assumed to be uncorrelated and each sequence is described by an independent probability density function. The signal is considered to be additive to noise and correlated among channels.

Dropping for simplicity the time dependence n, each sample of the process can be represented as a p-dimensional vector $\mathbf{x}_i$ with components

$$\mathbf{x_i} = [x_{1i}, x_{2i}, \dots, x_{pi}] \qquad (2)$$

Noise presence causes random variations of both the vectors amplitudes and their relative angles . It has to be filtered out, preserving the time correlation present to the signal.

Distance depended filtering has data smoothing and order preserving capabilities and was used at first with 1-D sequences [3]. Filtering i.e. along one of the X_i 's , with an 1xN window, the weighting coefficient c_j of the x_j sample is given by

$$c_j = f(d_j), \quad \text{where} \quad d_j = \sum_{j=1}^{N} \left\| \mathbf{x} - x_j \right\| \qquad (3)$$

where **x** is the one dimensional vector of N real successive observations. The function f is basically an inverting function giving less weight to distant samples. Throughout this work $f=1/d^k$, (k=2), is used.

Extending to the vector case, a pxN filter window W is defined. The weighting coefficient v_i of the i sample, which is now the p-component vector $\mathbf{x_i}$, is

$$v_i = f(D_i), \quad \text{where} \quad D_i = \sum_{i=1}^{N} \left\| \mathbf{x} - \mathbf{x}_i \right\| \qquad (4)$$

where **x** is the set of N vectors included in W, each one having p-components. Thus the distance D_i is the aggregate distance of the vector $\mathbf{x_i}$ and the other vectors $\mathbf{x_j}$ of the set within W. In this relation, $\| \ \|$ denotes the Euclidean distance (L_2. norm) The L_1 norm is also used. It should be noticed that D_i is a scalar and all components of vector $\mathbf{x_i}$ are weighted by the same coefficient v_i.

The output is the sum of the weighted vectors

$$\mathbf{y} = \sum_{i}^{N} v_i \mathbf{x_i} \qquad (5)$$

This type of vector weighting filtering has two implications.

i) Time correlation is preserved. This is a much needed characteristic when filtering vector processes.

ii) When vector $\mathbf{x_i}$ is an outlier , it is attenuated by proportionally scaling down all its components. This will reduce its contribution to the resultant vector.

Vector $\mathbf{x_i}$ can be an outlier if its amplitude $||x_i||$ or angle è$_i$ or both, deviate significantly from those of other vectors in W. Angle è$_i$ is the total angle of vector $\mathbf{x_i}$ to all the others within W and can be used as another deviation measure.

It is interesting to examine some characteristic cases concerning $\mathbf{x_i}$ and its corresponding distance D_i and angle è$_i$.

a) The values of all the components of $\mathbf{x_i}$ significantly deviate from those of the other vectors in W.

Such a case exists when W is located at an edge and $\mathbf{x_i}$ either belongs to the minority part of the edge or when $\mathbf{x_i}$ is an impulse, present to all p-components. In this case distance D_i will have a large value. This type of outlier vector will have in general a small angle deviation è$_i$

b) Vector $\mathbf{x_i}$ has a large angle deviation but its amplitude $||x_i||$ does not deviate significantly. Again D_i will have a large value. In color image processing this is the case of chromaticity edges without an accompanying intensity. edge

c) Vector $\mathbf{x_i}$ has both large angle and amplitude deviation. This can occur when a single outlier is present in one of the vector's components. D_i will also have a large value. Such a case is illustrated in Fig.1(a), where for simplicity the vector dimension p is taken equal to two. Original and distance weighted vectors are indicated.

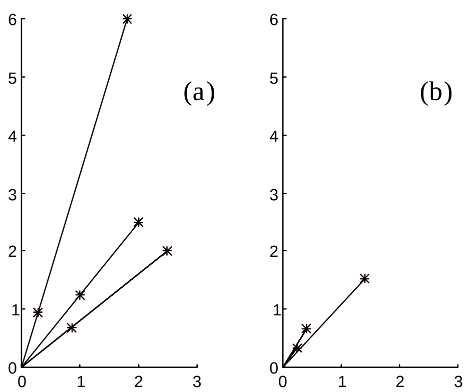

Figure 1. Distance filtering of three vectors, each one with two components (p=2) Original and distance weighted vectors are displayed in (a), while weighted vectors with the new composite distance (CD=d*D) are shown in (b) . In both cases, the filtered output vector is the sum of weighted vectors.

It is a common characteristic of all of the above cases, that an outlier presence will be associated with a large value of D_i. Outliers are subsequently attenuated by the distance filter of eq.(5).

A shortcome of the method is that it can only scale vectors amplitudes and has no influence to their angle è$_i$ (has no angle shifting capability). This disadvantage is portrayed in Fig.1 where, although just a single component value in one of the vectors is uncorrelated, the whole vector is either disregarded or attenuated. In addition, after being weighted the outlier vector will be still pointing to the wrong direction. Distance vector filtering will just attenuate the outlier vector.

To overcome the problem, a combination of vector and componentwise filtering is proposed in this work. This is achieved using a new composite distance

$$CD_{ij} = g(d_{ij}, D_{ij})$$
$$\text{where } g = d_{ij} * D_{ij} \text{ or } g = D_{ij} + d_{ij} \qquad (6)$$

The new distance CD_{ij} is a function of both the componentwise distance d_{ij} and the vector distance D_{ij}.. Among possible combinations the product and sum distances are examined here.

The new filter coefficients are defined as

$$r_{ij} = f(CD_{ij}) \qquad (7)$$

and form now a pxN matrix. It should be noticed that filter coefficients have to be normalised along each one of the p signal components in order to preserve its total power.

The algorithm has now both amplitude and angle shifting capabilities. At the same time, vector correlation is preserved. A filtering example using the new composite distance on the same set of input vectors is illustrated in Fig.1(b).

IV FILTERING PERFORMANCE

The proposed new filter was tested using real and simulated multivariate data. In the case under consideration the true shape of the original SES signal is unknown. What is usually received is a signal modified by the varying characteristics of the specific earth's propagation path.

A typical four channel SES signal recorded by the VAN station in Patras area [6], is illustrated in Fig.2.

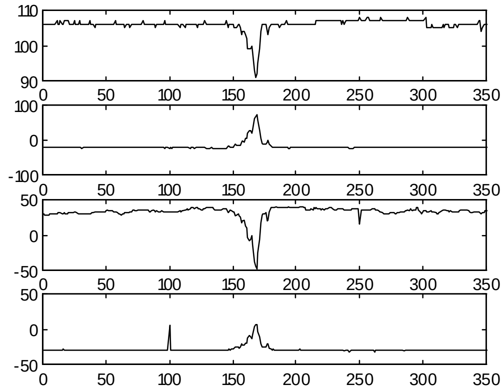

Figure2. An SES signal received by the VAN station in Patras area. Signal amplitude levels are in mvolts. and no prior amplification is used. Sampling interval of the horizontal axis is 20 sec.

For simulation purposes correlated multichannel pulse type signals were used. These included both positive and negative edge gradients occurring simultaneously in all channels with different polarities, different signal amplitudes levels and different noise variances. Although a detailed study for the most appropriate noise model has not been carried out yet, from lengthy observations, a suitable model seems to be one having a long tailed multivariate distribution.

Applied to real and simulated data, the new filter, using the product of distances, had better edge preserving and impulse suppression properties than the ordinary distance filter. The sum of distances filter had a better noise smoothing performance for Gaussian noise. Both filters preserved time correlation of edges.

TABLE I

Filter type N=5	Gaussian NR-dB	Laplacian NR-dB
D-filter	6.54	7.44
D+d filter	6.50	7.69
D*d filter	5.94	7.85

Simulation results using 1-D noise sequences are shown in Table I. A five channel signal was used. Noise sequences were uncorrelated with Gaussian or Laplacian distributions and different dc signal values were added to each channel. The composite distance filter is compared to the ordinary distance weighted multichannel filter, since the latter has proved superior to both the marginal and vector median filters. Comparisons were made using the noise reduction index (NR) as defined in [8]. It is the ratio of the output to input noise power in dB.

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