AN EFFICIENT TECHNIQUE FOR STORING EDDY CURRENT SIGNALS

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INTRODUCTION

Preventive maintenance schemes often involve periodic inspection of plant and equipment in industry. Evaluation of the integrity of the plant at regular intervals provides data not only for the detection of defects in their incipient stages but also for monitoring the evolution in the growth of defects that were considered benign in previous inspections. Evolution in the nature of defects is tracked by comparing the signals obtained with test data obtained and recorded from previous tests. Consequently the procedure entails storage of a large amount of data during each inspection. As an example, the Nuclear Regulatory Commission mandates periodic inspection of steam generator tubing in nuclear power plants using eddy current techniques. The signals are recorded on a multichannel analog tape recorder with one of the tracks dedicated for storing the voice of the operator who records the details of the test conditions. A major disadvantage of this approach lies in the voluminous nature of the data necessitating the use of a large amount of storage media. In addition it is difficult to address and access specific data records.

An alternative method involves sampling the signal and recording the digitized signal. The method results in lower distortion if appropriate sampling frequencies and word lengths are used to represent the signal. In addition, it is relatively simple to access individual records if suitable headers are attached to them. However, the method shares the disadvantage of requiring significant storage media since no attempt to compress the information in the stored signal is made. This paper presents a simple technique capable of compressing the information contained in a signal significantly. Results demonstrating the potential of the method are also presented.

SIGNAL MAPPING AND COMPRESSION

The method described in this paper shares a philosophy that has been used to compress speech signals extensively [1]. The objective is accomplished in two stages as shown in Figure 1. The first stage involves mapping of the signal onto an appropriate parameter space using a suitable model. The parameters are coded efficiently to achieve additional compression and stored. Signals are reconstructed using the coded coefficients in the model.
PARAMETER ESTIMATION  PARAMETER CODING SCHEME
EDDY CURRENT SIGNAL  COMPRESSED DATA

Fig. 1. Mapping and compression scheme for storing signals.

The degree of compression and the quality of reconstruction hinge on the appropriateness of the model relative to the signal. As an example, ultrasonic signals can be represented using Autoregressive models. Eddy current impedance plane trajectories can be modelled using Fourier descriptors or Circular Autoregressive models. In all these cases the process of mapping yields a compact representation containing a minimal amount of redundant information. This paper demonstrates the feasibility of using this general approach by examining a specific application involving eddy current signals and using the Fourier descriptor method for mapping.

FOURIER DESCRIPTORS

The use of Fourier descriptors for the representation and classification of impedance plane trajectories has been reported elsewhere [2,3]. However, for the sake of completeness, a brief description of the method follows.

Consider a closed curve as shown in Figure 2. If we define the contour function \( u(\ell) \) as

\[
u(\ell) = x(\ell) + jy(\ell)
\]

where \((x(\ell), y(\ell))\) represent the coordinates of a point in the impedance plane \( \ell \) arc length units away from an arbitrary starting point \( P_0 \), then

\[
u(\ell) = u(\ell + L)
\]

where \( L \) is the total length of the closed curve. Equation 2, which is valid since the curve is closed, indicates that the function \( u(\ell) \) is periodic with period \( L \). Consequently \( u(\ell) \) can be expanded in a Fourier series

\[
u(\ell) = \sum_{n=-\infty}^{\infty} C_n \exp\left(\frac{j2\pi n \ell}{L}\right)
\]

where

\[
C_n = \frac{1}{L} \int_0^L u(\ell) \exp\left(-\frac{j2\pi n \ell}{L}\right) d\ell
\]

Compression is achieved by computing only a limited number of coefficients, \( C_n \). These coefficients can be substituted in a finite version of the sum in equation (3) to resynthesize a curve which approximates the original curve closely.
The quality of reconstruction is directly related to the number of coefficients $(2M+1)$ used in the resynthesis equation with the trade off being the degree of compression. Smaller values of $M$ lead to a higher degree of compression at the expense of the quality of reconstruction.

The coefficients cannot be computed directly using Equation 4 since we have only a sampled version of $u(t)$. Instead the trajectory is approximated by a polygon of $m$ sides with the vertices located at the sample points as shown in Figure 3 and the following expression used for calculating the coefficients [3,4].

$$u(t) \approx \sum_{n=-M}^{M} c_n \exp\left(\frac{j2\pi n k}{L}\right)$$

$$c_n = \frac{L}{4\pi^2 n^2} \sum_{k=1}^{m} (b_{k-1} - b_k) \exp\left(-\frac{j2\pi n \xi_k}{L}\right), \quad n=0$$

where

$$\xi_k = \sum_{i=1}^{k} |v_i - v_{i-1}|, \quad k>0, \quad \xi_0 = 0$$

and

$$b_i = \frac{v_{k+1} - v_k}{|v_{k+1} - v_k|}$$

Fig. 3. Polygon of $m$ sides approximating the curve.
CODING

Additional compression is achieved by coding the Fourier coefficients efficiently. However, coding schemes using the conventional floating point format cannot be employed since the dynamic range of the coefficients is very large. This is due to the fact that the trajectories are very smooth and consequently the coefficients decay at a rate faster than $1/n^2$. Recognizing the large dynamic range, the coefficients are coded using the mantissa/exponent form with 3 bits reserved for the exponent. The number of bits used for the mantissa was then varied and the quality of reconstruction evaluated.

RESULTS

In order to assess the performance of the approach, the method was first applied to a lemniscate of Bernoulli synthesized by using the expression

$$r^2 = a^2 \cos 2\theta$$

(7)

in a polar coordinate system.

Figure 4 shows the quality of reconstruction obtained by using progressively smaller number of bits in the mantissa. It is clear that the quality deteriorates rapidly when fewer than 8 coefficients are used. The method was then used to compress information contained in an eddy current signal obtained from a test arrangement consisting of an inconel tube with a through wall hole defect located at the center of a support plate as shown in Figure 5 with $d=0.0$. The trajectory obtained represents a composite signal consisting of the support plate and defect signals. Figure 6 shows the quality of reconstruction as a function of the number of bits in the mantissa. Figure 7 shows results obtained with a signal due to a through wall hole defect in an inconel tube. In all the cases it is seen that the performance is satisfactory when the number of bits used is 8 or larger.

The signal shown in Figure 6 was obtained by sampling each channel at the rate of 2000 samples per second using an A/D converter with 12 bit resolution. Fourier coefficients of the trajectory containing 300 points were then computed and coded. If we use 16 Fourier coefficients and employ 8 bits in the mantissa the total number of bits required is 456. This implies that a compression ratio of 15.8 has been achieved. Higher compression ratios can be achieved for simpler trajectories.

Figures 8 and 9 show results of attempts at compressing information by undersampling the original signal and using fewer bits. It is clear that the performance of the method proposed in this paper is superior. This is due to the fact, that in the process of mapping the signal to the parameter space most of the redundant information contained in the signal is eliminated.
Fig. 4. Reconstructed signal obtained by using 8 Fourier coefficients and varying number of bits in the mantissa.

Fig. 5. Defect and support plate arrangement used to generate eddy current signal.
Fig. 6. Signals reconstructed using 16 Fourier coefficients and varying number of bits in the mantissa.
Fig. 7. Signals reconstructed using four coefficients and varying number of bits used in the mantissa.

Fig. 8. Eddy current impedance plane track sampled at a) 2000 samples/second, b) 660 samples/second, c) 300 samples/second and d) 150 samples/second.
Fig. 9. Signal obtained by quantizing the impedance plane trajectory, using a) 8 bits, b) 5 bits, c) 4 bits.

CONCLUSIONS

A simple technique involving a two step procedure has been presented. Significant compression can be achieved using the method with little loss in quality resulting in considerable savings in the amount of storage media required. Access to individual records can be made easy by attaching headers to the record.

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REFERENCES


