

XXV. SIGNAL PROCESSING*

Academic and Research Staff

Prof. A. G. Bose
Prof. J. D. Bruce

Prof. D. E. Nelsen
Prof. A. V. Oppenheim
Prof. C. L. Searle

Prof. H. J. Zimmermann
Dr. M. V. Cerrillo

Graduate Students

J. B. Bourne
M. Bruce-Lockhart
M. F. Davis

D. A. Feldman
R. M. Mersereau
T. L. Rhyne

J. R. Samson Jr.
L. M. Sivertson
R. E. Stewart

RESEARCH OBJECTIVES

This research relates to the recording, processing, and reproduction of acoustic and visual signals. Included are studies that consider nonlinear and time-variant filtering, using analog or digital techniques.

Various experiments conducted over many years have indicated that small changes in physical signals apparently yield relatively large changes in perceptual response. Attempts are being made to obtain more quantitative measures of these effects. The results of these studies are potentially important to the improvement of performance in communication systems.

1. Digital Processing of Analog Signals

This research concerns the development and application of techniques for processing analog signals using a general-purpose digital computer and special-purpose digital hardware. Signal processing using digital hardware is playing an increasingly important role, because of the inherent flexibility and reliability of digital processing coupled with lowering cost and size resulting from the development of integrated circuit technology. Applications for digital processing techniques can be drawn from a variety of areas including speech-waveform processing, radar signal processing, and enhancement of images such as photographs and medical x-rays. In particular, we shall consider the following topics.

- a. Design of nonrecursive digital filters.
- b. The effect of finite register length in digital filtering and spectrum analysis.
- c. Implementation of two-dimensional Fourier transforms.
- d. Applications to speech processing and x-ray enhancement.

2. Signals and Perception

Further consideration of the experiments made by Dr. M. V. Cerrillo with acoustical and visual signals has led to three areas of research: time-variant linear processing of music signals, removal of multipath echoes from a signal by window-function processing, and computer generation of visual patterns by exploitation of symmetry.

A multichannel music system has been constructed to examine the subjective effects of modifying certain parameters of the "envelope" of a music signal. By modifying the

*This work is supported by the Joint Services Electronics Programs (U. S. Army, U. S. Navy, and U. S. Air Force) under Contract DA 28-043-AMC-02536(E).

amplitude, first derivative, and second derivative of the signal envelope appropriately, it is possible to influence the contrast, the attack, and the percussive effects in the music. Current work is directed toward design of an improved detector system.

The problem of echo-removal provides an interesting example of the application of Cerrillo's linear systems synthesis methods using window functions.¹ We are now undertaking computer studies of the advantages and limitations of echo-removal systems synthesized in this manner. Preliminary work indicates that the method has potential applications to some practical signal-processing problems. Further work is necessary, however, to establish meaningful comparisons with other methods.

More than a decade ago, Cerrillo performed experiments which, in effect, constituted plausibility arguments for explaining various functions of the brain in terms of specific system models. One of these studies considered the type of information the eye-mind system extracts from a visual scene in order for a person to recognize the scene and store it in his memory. In one aspect of this study he used generalized symmetry considerations to generate visual patterns. His purpose was to show that the perceptual mechanism tends to seek symmetries in patterns. He used an apparently random arrangement of dots which actually contained symmetries. The construction of such patterns by Dr. Cerrillo was a time-consuming process. During the past year a Master's thesis student succeeded in generating similar patterns using a computer display system.² This technique permits rapid generation of dot patterns that can be conveniently varied to study perceptual effects. This work clearly indicates that symmetries play an important role in the perception of visual images. For example, Smith was able to generate crude facial images using a single topological transform and an image grid that had been devised by Cerrillo.

These studies can now be extended in several ways. Parameters, such as the spacing, size, and number of dots, should be varied to obtain a better understanding of the relationship between pattern elements and the underlying symmetries. Furthermore, the use of curvilinear geometries as topological transforms would remove some of the limitations imposed by the use of linear transforms.

3. Signals, Noise, and Systems

Two students who have had extensive industrial experience with the Loran-C navigation system have initiated studies of several practical problems encountered in connection with it. The questions involve such matters as appropriate criteria for specification and design of the receiver when interference is non-Gaussian natural and man-made noise, the application of digital filtering techniques in the receiver design, and the possibility of using various nonlinear filter techniques. Most of the questions being studied have implications for systems other than Loran-C.

4. Noise in Switching Circuits

Mechanisms contributing to switching-time jitter in regenerative bistable devices and circuits have been the subject of investigation for several years. Models relating time jitter to more fundamental shot, thermal, and $1/f$ noise processes in the circuit components have been found for the tunnel diode switch and for a class of Schmidt trigger circuits.

Work on this problem continues. A family of nonlinear, dynamic differential equations relating dynamic switching variables to circuit noise is being studied. These equations are interesting, in that regeneration in the physical switch corresponds to the solution's infinity. In control problems this kind of divergence is classified as an instability, and is generally not considered further. Much of this investigation is being carried out with the aid of a digital computer. In some regions of operation, the

solutions of these equations approach those of the classic first-passage time problem, involving the determination of statistics of the first zero passage of a ramp on which stationary noise has been superposed.

A. G. Bose, J. D. Bruce, D. E. Nelsen, A. V. Oppenheim
C. L. Searle, H. J. Zimmermann

References

1. M. V. Cerrillo, "On the Mode of Convergence and Its Correction by Methods of Linear Summability," Technical Report 269, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., May 3, 1950; see Appendix.
2. J. F. Smith, "A Computer Investigation of Symmetry in Images," S.M. Thesis, Department of Electrical Engineering, M.I.T., August 1970.

A. FREQUENCY- AND TIME-DOMAIN ANALYSIS OF WINDOW ARRAYS

We have been studying in detail the time-domain and frequency-domain characteristics of certain "window function" operators, as developed by M. V. Cerrillo.¹ The results have been published in a Master's thesis.² In this thesis, the general operator, constructed of evenly spaced impulse windows, is derived in the time domain, and general techniques are developed for singularity analysis and transfer-function frequency response analysis. These techniques are used to analyze the four basic operators: pure transmission, differentiation, delay, and prediction. Numerical examples for each operator are included, as well as computer programs written in APL, which were used to obtain numerical results; these results are compared with ideal operators. Two other topics are considered briefly: operators with perturbed window areas, and operator determination from zero constellations.

R. K. Stockwell

References

1. M. V. Cerrillo, "On the Mode of Convergence and Its Correction by Methods of Linear Summability," Technical Report 269, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., May 3, 1950, pp. 122-147.
2. R. K. Stockwell, "Frequency and Time Domain Analysis of Window Arrays," S.M. Thesis, Department of Electrical Engineering, M.I.T., January 1970.

B. APPLICATION OF WINDOW FUNCTIONS TO THE DETECTION OF A SIGNAL IN THE PRESENCE OF ECHOES

To extract a transmitted signal $f(t)$ from a received signal $g(t)$ corrupted by echoes,

$$g(t) = f(t) + b_1 f(t-T_1) + b_2 f(t-T_2) + \dots, \quad (1)$$

it is necessary to pass $g(t)$ through a filter with transfer function

$$H(s) = \frac{1}{1 + b_1 e^{-sT_1} + b_2 e^{-sT_2} + \dots}. \quad (2)$$

Synthesis of this transfer function is being investigated, with the use of the techniques developed by M. V. Cerrillo in his theory of window functions.¹ Initial work is concerned with the simpler case of removal of a single echo using the transfer function

$$H(s) = \frac{1}{1 + b e^{-sT}}. \quad (3)$$

In general, a frequency function $H(s)$ can be realized as a window function by expanding $H(s)$ as a Taylor series about $s = 0$, which together with a specification of the impulse spacing δ can be used to determine the weights a_i of the impulses in the window function. Cerrillo has shown that the weights a_i for the echo-removal transfer function depend only on the number of impulses, n , used to approximate $H(s)$ and the ratio T/δ , where δ is the spacing of the windows. One of the aims of the present research is to investigate the performances of window function approximations of $H(s)$ for fixed n and varying δ in removing echoes from lowpass signals characterized by specific delays T , echo amplitude b , and bandwidth ω_m . In particular, we wish to determine the relationship between the limits of these signal parameters beyond which successful echo rejection cannot be achieved.

The studies are being carried out using a computer simulation of the window-function realization of $H(s)$, with test signals comprised of sums of sinusoids at arbitrarily chosen frequencies and pseudo-randomly chosen amplitudes. As the work progresses, signals more typical of those found in echo-removal applications will be used. Evaluation of the performance of the filters is based on rms error calculations, as well as visual comparison of desired, corrupted, and recovered waveforms. Future research will be concerned with the problems of removal of multiple echoes with an attempt to determine what improvements in frequency response and phase-shift characteristics can be obtained by cascading the echo-removal filter with other filters.

J. B. Bourne

References

1. M. V. Cerrillo, Technical Report 269, Research Laboratory of Electronics, M. I. T., Cambridge, Mass., May 3, 1950, pp. 122-139.