MACHINE IDENTIFICATION OF WAVEFORM CHARACTERISTICS, WITH APPLICATION TO SEAT MOTION

A.J. Brammer,[1] G. Roddan,[2] J. Village,[2] and J. Morrison[3]

[1]Inst. for Microstructural Sciences, National Research Council, Ottawa, Ont.
[2]British Columbia Research Corporation, Vancouver, B.C.
[3]School of Kinesiology, Simon Fraser University, Burnaby, B.C.

1. Introduction

The purpose of this paper is to propose a method for distinguishing randomly occurring impulses and other intermittent or transient waveforms from a background of near-sinusoidal or Gaussian random signals, all with zero mean value. It involves computation of the higher-order root mean values and impulsiveness of the waveform, represented by a time series, and a measure of the tonal quality of its frequency spectrum. The procedure relies on establishing the statistics of the time series and is related to some techniques for signal detection,[1] for which purpose frequency domain and autocorrelation methods may be preferred for periodic impulses.[2]

The method has been used to establish the character of vibrations recorded at the seats of off-the-road vehicles, to provide information concerning potential health effects.[3]

2. Method

2.1 Higher-order mean values

The probability that the instantaneous magnitude of a time series $\mathbf{x}(t)$ falls within a narrow interval Δx, as illustrated in Figure 1A, is given by the probability density function (pdf):[4]

$$p_x(x,t) = \lim_{|\Delta x| \to 0} \frac{\text{Prob}[\mathbf{x}(t) \in \Delta x]}{|\Delta x|} \qquad (1)$$

For non-stationary signals, the pdf will depend on the time at which the function is evaluated. The expected values of the time series at time t are defined in terms of second-, and higher-, order moments of the pdf:

$$E(x^n,t) = \int_{-\infty}^{\infty} x^n p(x,t)dx \qquad (2)$$

where $n = 1,2,3..etc.$ The corresponding root mean values are then:

$$[E(x^n,t)]^{1/n} = \left[\int_{-\infty}^{\infty} x^n p(x,t)dx\right]^{1/n} \qquad (3)$$

Relationships may now be derived between the n^{th} even-order root mean value and the root mean square (RMS) value, $x_{\mathrm{RMS}}(t)$. These will depend on the shape of the pdf, which in turn will depend on its time series. For signals with a Gaussian random distribution and zero mean value during the time interval of interest:[4]

$$\frac{[E(x^n,t)]^{1/n}}{x_{\mathrm{RMS}}(t)} = \left[\prod_{k=1}^{n/2}(2k-1)\right]^{1/n} \qquad (4)$$

For such signals, the twelfth-order root mean value $x_{\mathrm{RMT}}(t)$ (i.e. $n = 12$ in equation 4) is related to the RMS value by:

$$x_{\mathrm{RMT}}(t) = 2.16 x_{\mathrm{RMS}}(t) \qquad (5)$$

and corresponds to a cumulative probability of $P(x) = 0.97$.

2.2 Impulsiveness

The introduction of impulses will cause the probability distribution of the composite time series to deviate from that of the original signal. An example is shown in Fig. 1. In this diagram, the probability distribution of the time series in Fig. 1A is shown by the thick line in Fig. 1B, while those of its constituent impulse and Gaussian random signals are shown by the thin and dotted lines, respectively. Changes in a random distribution, such as that resulting from the occurrence of an impulse (i.e. from dotted to thick lines in Fig. 1B), will be reflected in the relative magnitudes of the expected values, which will hence deviate from the ratios in equation 4.

An alternative measure of signal magnitude that retains a specific probability value is obtained from the impulsiveness. This measure is defined in terms of positive and negative amplitudes of the time series, $x^+(t)$ and $x^-(t)$, at selected probability values which for the purposes of the present work are chosen to be $P(x,t) = 0.985$ and $P(x,t) = 0.015$, respectively:

$$I_{(0.97)} = \frac{x^+(t) - x^-(t)}{2x_{\mathrm{RMS}}(t)} \qquad (6)$$

The impulsiveness provides a measure of the magnitude of amplitude excursions, including impulses, exceeded a specified fraction of the time, as can be seen from Fig. 1B. Hence, values of $I_{(0.97)}$ and $x_{\mathrm{RMT}}(t)/x_{\mathrm{RMS}}(t)$ for a time history of unknown characteristics will provide information on its waveform. Reference to Fig. 1 shows that the impulse has resulted in an increase in the former by a factor of 1.1 and the latter by 1.4 compared with the values for a Gaussian signal (2.16). These two parameters, together with a simple test for tonal components in the frequency spectrum,[3] may hence be used to characterize waveform signatures.

3. Results and Discussion

Computer recognition of different waveform characteristics has been explored by analyzing acceleration time histories recorded at vehicle seats, with a separate measure of the tonal content.[3] The basic requirement was to distinguish waveforms containing impulses from other signals (as illustrated by Fig.1). Four waveform signatures were identifiable by the method described: 1) Gaussian random motion; 2) periodic or almost periodic near-sinusoidal motion, which may be amplitude modulated; 3) intermittent motion - non-stationary random and transient deterministic signals; and 4) impulsive motion including shocks. The values of the parameters used to establish the four signal types are given in Table 1, where the peak-to-mean ratio of spectral components is SPECF. Note that signal types 2 and 3 are derived from two alternate conditions indicated by "or".

A subjective visual typing of 160 waveform signatures from off-the-road military vehicles was made by a jury of two observers, who examined each in sequence. The subjective typing was established by agreement between the observers. Although there were 10 records that were considered borderline between signal types, all but one were adjudicated in favour of the typing performed by the computer, which was known to the observers. Hence, machine typing of seat motion signatures was considered to be satisfactory in most cases and, at worst, resulted in 10/160 errors.

Acknowledgements

Part of this work was performed for the United States Army Aeromedical Research Laboratory under contract DAMD17-96-R-0142.

Table 1: Tests for Seat Motion

Motion Type	RMT/ RMS	I(0.97)	SPECF
1	> 2.0 < 2.5	< 2.3	< 4.0
2	≤ 2.0		
or	> 2.0 < 2.5	< 2.3	≥ 4.0
3	≥ 2.5	> 2.6	
or	> 2.0 < 2.5	≥ 2.3	
4	≥ 2.5	≤ 2.6	

References

1. S.A. Kassam, "Signal Detection in Non-Gaussian Noise", Springer-Verlag, New York (1988).
2. R.F. Dwyer, "Extraction of helicopter-radiated noise by frequency domain processing", J. Acoust. Soc. Am. **78**, 95-99 (1985).
3. G. Roddan, A.J. Brammer, J. Village and J. Morrison, "Development of a standard for the health hazard assessment of mechanical shock and repeated impact in army vehicles: Phase II Report", Report DAMD17-90-R-0142, for U.S. Army Aeromedical Research laboratory, Fort Rucker, AL (1993).
4. J.S. Bendat and A.G. Piersol, "Random data: Analysis and Measurement Procedures", Wiley, New York (1986).

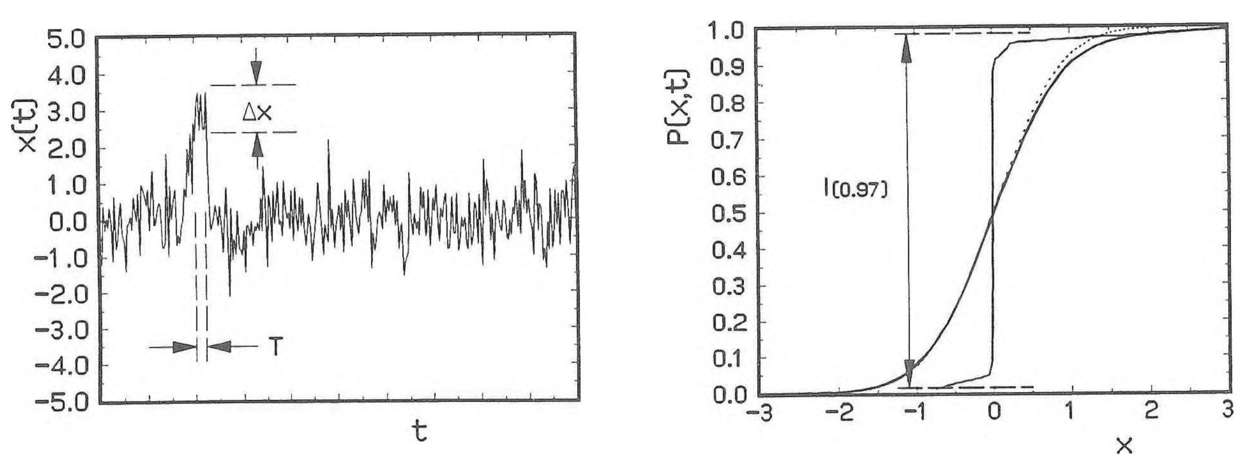

Figure 1: A - Impulse in a Gaussian random time series with magnitude in the range Δx for time T; and B - Probability distribution for this waveform (thick line), together with those of its constituent impulse (thin line) and random signal (dotted line). The values of $x_{RMT}(t)/x_{RMS}(t)$ and $I_{(0.97)}$ for the time series shown in A are 3.02, and 2.37, respectively, and 2.16 for the Gausian signal.