AN ON-LINE REACTOR SURVEILLANCE ALGORITHM
BASED ON MULTIVARIATE ANALYSIS OF NOISE*

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MASTER

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*Research sponsored by Energy Research and Development Administration under contract with the Oak Ridge National Laboratory operated by Union Carbide Corporation.

A mini-computer based surveillance algorithm for monitoring signals from nuclear power plants to provide advanced warning of anomalous conditions has been developed and implemented for on-line applications. The reactor state is characterized by the analysis of noise signals.⁽³⁾ During an observation period when normal conditions prevail, the surveillance algorithm utilizes these noise characterizations to form a statistical description of normal reactor behavior. At the conclusion of this observation period, the surveillance algorithm examines each new incoming characterization to determine if it differs significantly from the normal description.

The surveillance algorithm represents a general statistical approach and is widely applicable to the various type descriptors of any noise signal. Thus far, the noise descriptor receiving the emphasis in this effort has been the power spectral density obtained using Fast Fourier Transform techniques. The power spectral density estimates are arranged into an n-dimensional measurement vector, $\underline{X}$, which characterize the reactor state.

In a complex system which operates over a wide range of conditions, a single noise signature would probably not be able to characterize all normal situations. Under these circumstances, the operating conditions for which there is significant variation in the signatures must be identified. These imposed operating conditions must be described by a set of discrete ranges during which the noise signature experiences only statistical variations. The noise signatures for each of these operational ranges are placed into separate data classes.

The surveillance algorithm identifies normal regions corresponding to each data class from the statistical description formed while observing normal operation of the reactor. The statistical description of a data class, ω_k , is based upon the mean vector, $\underline{\mu}_k$, and a covariance matrix, C_k , calculated from a population sample. A hyperellipsoid constructed using these sample statistics is given by

$$(\underline{X} - \underline{\mu}_k)^T C_k^{-1} (\underline{X} - \underline{\mu}_k) = G^2 \quad (1)$$

where the value of the constant, G , determines the volume enclosed.⁽²⁾

The hyperellipsoid corresponding to each data class acts as a partitioning surface and encloses the normal space for that class.

If a measurement vector belonging to that data class falls outside of this hyperellipsoid enclosure, the state of the reactor is suspect.^(3,4)

The effectiveness of the surveillance algorithm has been demonstrated by (a) several well controlled bench tests, (b) deterministic test on-line at the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory, and (c) on-line demonstration at the Georgia Power Electric Company HATCH (BWR-4) plant. The results from a typical bench test are presented in Figure 1. The abnormality in the test was the removal of the damped resonant information in the 4 hz range. For the system shown in Figure 1, all normal measurement vectors had G^2 values less than 75 (the apriori determined criterion value for comparison with the calculated G^2). Clearly, G^2 values ranging from 200 to 800 indicate significant changes in the measurement vector (power spectra in this case) and cause the state of the system to be suspect. Results from the tests performed at HFIR and the demonstration at HATCH were equally successful and will be presented.

A surveillance algorithm capable of automatically assessing the normality of system behavior by examining noise data of high dimensionality has been developed, implemented, and evaluated for continuous on-line application. This capability removes the awesome task of continuous operator evaluation of the volumes of data (spectra, for example) which are normally associated with on-going surveillance programs. -- ----

REFERENCES

1. Paul W. Cooper, "Hyperplanes, Hyperspheres, and Hyperquadrics as Decision Boundaries," Computer and Information Sciences, Spartan Books, Inc., Washington, D. C., 1964.
2. S. Johns, "A Tolerance Region for Multivariate Normal Distribution," Sankhya, 25: 363-368 (1963).
3. "Power Reactor Surveillance and Diagnostics by Noise Analysis," Tennessee Industries Week course, The University of Tennessee, September 1974.
4. Maurice M. Tsatsuoka, Multivariate Analysis: Techniques for Educational and Psychological Research, John Wiley & Sons, Inc., New York, 1971.

FIGURE 1

REMOVED SIGNAL FROM 3 HZ BANDPASS FILTER

{No Grid}

POWER SPECTRAL DENSITY ($\frac{\text{Volts}^2}{\text{Hz}}$)

LEGEND

NORMAL MEAN VECTOR

Learned from 157 History Vectors
RMS = .1253v.

ABNORMAL VECTORS

$G^2 = 193.7$
RMS = .1179v. } Group these
 $G^2 = 739.8$
RMS = .1204v. } different from

Tick marks

Tick marks

FREQUENCY (Hertz)