Condition Monitoring

Presented by:

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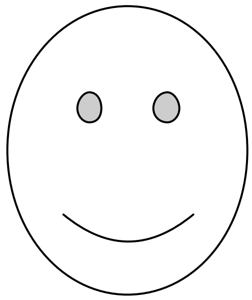
Outline

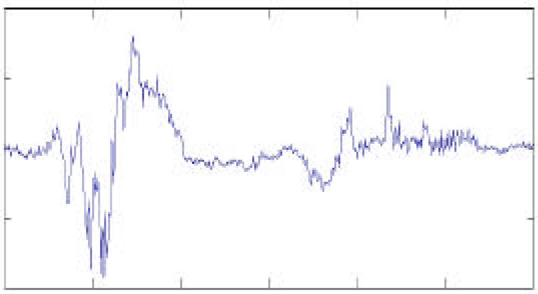
- Nonlinear technology behind condition monitoring
- Brief description of technical basis
- Commercialization of EEG/epilepsy forewarning device
- Many other potential applications
- Questions

Nonlinear Technology Behind Monitoring

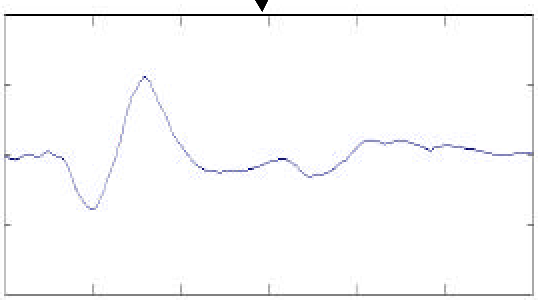
- U.S. Patent #5,626,145 Extraction of low frequency artifacts from EEG
- U.S. Patent #5,743,860 Epileptic seizure detection
- U.S. Patent #5,815,413 Integrated method for chaotic time series analysis
- U.S. Patent #5,857,978 Epileptic seizure prediction
- Patent application ERID0527 Nonlinear crack growth monitoring (9/24/00)
- Patent application ERID0694 Nonlinear condition assessment (3/8/00)



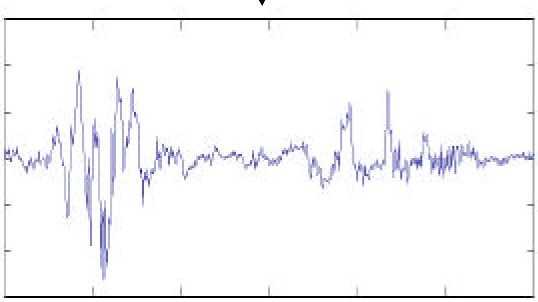
Multichannel scalp EEG data is acquired from human patients. An alphanumeric designation uniquely identifies each dataset to preserve patient anonymity. For example, the data in this example is from SZ13IN.



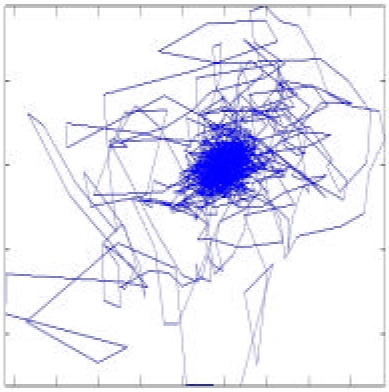
The nonlinear paradigm handles noisy experimental data that describes the brain dynamics. This figure shows raw EEG from channel C3 in the 10-20 International System at a sampling rate of 250 Hz. Tick marks are spaced at intervals of 0.5s.



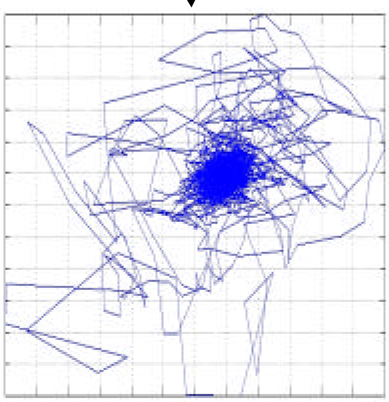
Low-frequency activity in scalp EEG is associated with eyeblinks and related muscular movements. This example shows removal of activity below 2Hz via a zero-phase, quadratic filter. This ORNL technology is covered by U.S. Patent #5,626,145, dated 6 May 1997.



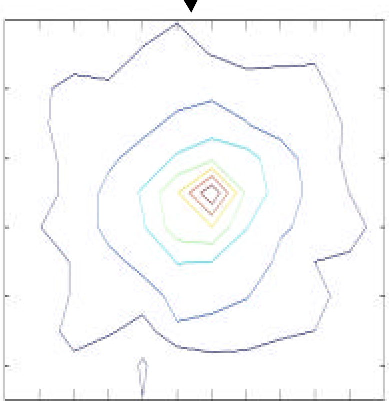
This figure shows the EEG signal after removal of the low-frequency artifact from the raw data. This method of artifact filtering retains all of the high-frequency nonlinear amplitude and phase information about the brain activity.



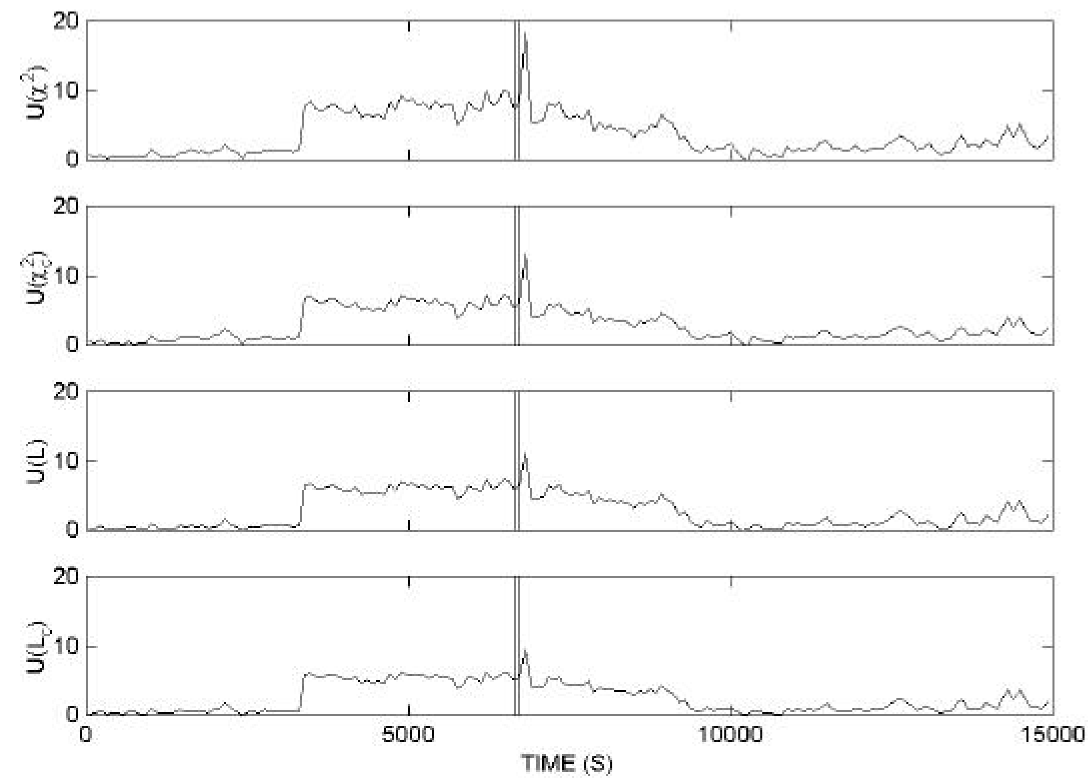
Artifact-filtered data (x_i) is converted to a phase-space (PS) form. This figure illustrates a two-dimensional version, showing lines between successive PS-points, (x_i, $x_{i+\lambda}$). The lag (λ) is chosen to best "unfold" the dynamics in this PS representation. The lag corresponds to the first minimum in the mutual information, which is the nonlinear analog of the autocorrelation function. This PS plot displays the structure of the nonlinear brain dynamics for 20,000 data points from dataset SZ13IN.



The phase-space is partitioned into equally-spaced bins in each dimension, as depicted in this figure. The method tabulates the number of PS states that fall into each bin. The result is a distribution function that statistically describes the shape and occurrence frequency of the brain activity over the phase space. This method is a discretized form of the natural measure of the PS attractor, which uniquely and robustly captures all of the nonlinear dynamics.



This figure illustrates logarithmically-spaced level contours of the PS distribution function (DF) that characterizes the artifact-filtered brain activity. A sufficiently high-dimensional PS captures all of the relevant brain dynamics within the limits of noise and sensor sensitivity. Typically, three dimensions and 20-40 discrete bins are sufficient for such data. The PS-DF method is covered by U.S. Patent #5,815,413, dated 29 September 1998.



These plots show nonlinear measures from the first clinical dataset that was acquired via the prototype seizure forewarning device. The vertical bars show the seizure duration from 6644 – 6705 seconds. All four measures show a clear change in the sample channel at 3520s, giving 52 minutes of seizure forewarning. The prototype gave no false-positive warnings prior to this event, which occurred on the seventh day of continuous EEG monitoring. The forewarning technique first removes eyeblinks and other artifacts that are superimposed on the brainwave activity. The method then converts the artifact-filtered data to a geometrical (phase-space) representation. A distribution function (DF) tabulates the location and occurrence frequency in a discrete form of this multidimensional phase space. The nonlinear measures show the dissimilarity between nonseizure DFs and DFs for subsequent time windows.

The prototype was developed jointly by Nicolet Biomedical Inc. and ORNL under a CRADA collaboration that began on 1 October 1999. The first prototype was installed at the epilepsy monitoring unit of the University of Wisconsin in Madison on 28 April 2000. Subsequent installations were at Strong Memorial Hospital in Rochester, New York (installed 6/15/00); Henry Ford Hospital in Detroit, Michigan (installed 6/23/00); Parklawn Hospital in Dallas, Texas (installed 6/29/00); and Med City Dallas in Dallas, Texas (installed 6/30/00). EEG data from these five clinical sites will be provided to ORNL for subsequent analysis.

The team members at Nicolet Biomedical Inc. are Dr. Jon Joseph (principal investigator), Todd Lucht, and Char Merican. The ORNL team members are Ned E. Clapp (Engineering Technology Division), Dr. Lee M. Hively (principal investigator, in the Engineering Technology Division), and Dr. Vladimir A. Protopopescu (Computer Science and Mathematics Division).

Many Other Potential Applications

- EEG for CNS pathologies, drug/chemical effects, head trauma, shock
- evoked EEG response for CNS/sensory diagnostic
- alertness/fatigue/stress/performance monitoring via EEG
- hands-free computer control via EEG with removal of muscular artifacts
- EKG for forewarning of cardiac fibrillation
- lung sounds for pulmonary pathology
- data fusion (EEG/EKG/body sounds ...) for physiological pathologies
- muscle tremors (3-axis acceleration) for neuromuscular pathologies
- statistical validation of model results with experiment
- vehicle acceleration (3-axis) for damage assessment by emergency responders
- earthquake prediction from 3-axis acceleration
- condition monitoring of machines for failure forewarning
- structural failure forewarning (crack growth) via hysteresis strain energy

Questions