ADVANCED PHYSIOLOGICAL MONITORING OF FCS SOLDIERS

L.M. Hively (hivelylm@ornl.gov) and V.A. Protopopescu
Oak Ridge National Laboratory, Oak Ridge, TN 37831-6418

Problem – One Future Combat Systems (FCS) requirement calls for an accurate and timely physiological monitoring system to report Soldier (dis)mounted medical status to unit leaders and medical personnel. Such monitoring requires continuous real-time assessment of each soldier's observable physiological status. Typical battlefield events include (but certainly are not limited to) drowsiness, excessive fatigue, dehydration, overwhelming stress, shock from battlefield trauma (e.g., blood loss from wound(s), broken bone(s), heat or cold exposure), and chemical/biological/radiological attack. Medical personnel cannot monitor the huge volume of continuous, real-time, physiological data from two thousand soldiers, so the monitoring system must include a capability for (quasi)-autonomous real-time analysis and assessment of the data.

Solution – ORNL has developed an advanced statistical methodology that forewarns of biomedical events from process indicative data, x(i), at time t(i) as follows. (1) Check the data for quality. (2) Remove confounding artifacts (e.g., eye blinks in brain wave data) by fitting a parabola in the least-squares sense over a moving window of length 2w+1, with w data points on each side of the current central point, and taking the central point of the fit as the best estimate of the low-frequency artifact, f(i). The residue, g(i) = x(i) – f(i) is essentially artifact-free. (3) Discretize the artifact-free signal, g_i, into one of S integer symbols between zero and S-1. (4) Create a d-dimensional vector, y(i) = [s(i), s(i+L), s(i+2L)…], using an appropriate time lag, L. (5) Tabulate the occurrences of this vector in the discretized d-dimensional phase space to obtain an approximate distribution function (DF) to capture the essence of the dynamics. (6) Repeat (5) for each contiguous, non-overlapping data segment to form DFs for the nominal (baseline) and sequel unknown (test) states. (7) Compare the baseline and test DFs via phase-space dissimilarity measures (PSDM). (8) Indicate condition change (failure forewarning) after a specific number of sequential occurrences of the PSDM above a threshold.

Results – PSDM provide consistently high discrimination of condition change for all of the applications to date. These applications include: (a) forewarning of human epileptic seizures from scalp brain waves; (b) forewarning of cardiac fibrillations and (c) fainting from human electrocardiogram (ECG) data; (d) detection of septic shock due to inhaled endotoxin from rat ECG data; (e) detection of breathing difficulty from pig chest sounds. Timely detection of physiological condition change for such diverse applications lends strong credibility to the robustness of this advanced methodology.

Status – The method involves high-fidelity laboratory integration of the basic technology elements into software that analyzes archival data on a desktop computer for event forewarning. The methodology handles limited, noisy, time-serial data (e.g., scalp brain waves, chest heart waves, chest sounds) and provides robust indications of change in the physiological dynamics (e.g., up to five hours forewarning of an epileptic event). The analysis is much faster than real-time, and can handle multiple streams of biomedical data (e.g., brain waves and heart waves). No special hardware is required, and the software adds no additional weight or bulk. ORNL has been granted six U.S. patents on the approach (with two additional patents pending). Consequently, the technology readiness level is 5 (TRL5).

Prototype – On-going development includes a graphical user interface and robust software implementation on a hand-held device (e.g., personal digital assistant) for on-line analysis of real-time data. We expect to complete these improvements in 2004, which would allow qualification for TRL6. Developments needed for TRL7 (suitable for clinical or field testing) involve primarily: (i) extensive statistical validation for specific physiological event(s) in an appropriate operational environment (measures of success include true-positive and true-negative rates, and the forewarning time distribution); and (ii) quasi-automatic determination of robust sets of parameters for analyst-independence.

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