ADVANCED PROGNOSTICS FOR FCS EQUIPMENT

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Problem – The Future Combat Systems (FCS) requirement 3.2.1.8.6.8 calls for an accurate and timely "Future System State Forecast." Such prognostication requires continuous real-time assessment of mission-critical systems and equipment to avoid failures via prompt predictive maintenance. Typical failures include (but are not limited to) cracking, misalignment, imbalance, short-circuits, broken gears, bearing faults, dust clogging, and wear from wind-blown dirt and sand. Maintenance personnel cannot track the huge volume of continuous, real-time data from hundreds of platforms in the Unit of Action, so the monitoring system must include a capability for (quasi)-autonomous real-time analysis and assessment of the data. The same statement is true for soldier-systems critical equipment.

Prognostics Solution – ORNL has developed an advanced statistical methodology that forewarns of equipment failures from process indicative data, x(i), at time t(i) as follows. (1) Check the data for quality. (2) Remove confounding artifacts (e.g., fundamental electrical sinusoid) 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 the applications to date. Applications to date include: (a) imbalance and misalignment seeded-faults in a motor-driven pump; (b) seeded faults in electric motors (air-gap offset, broken rotor, turn-to-turn short, and imbalance); (c) progressively larger drill bit wear; (d) distinction between different states for (un)balanced centrifugal pump; (e) progressively larger seeded crack in a rotating blade; (f) motor-driven gear failure (accelerated test); (g) motor-driven bearing failure (accelerated test); and (h) structural failure by cracking. Timely forewarning for such diverse applications lends strong credibility to the robustness of this advanced prognostic.

Status – The method involves high-fidelity laboratory integration of the technology elements into software that analyzes archival data on a desktop computer for failure forewarning. The methodology handles limited, noisy, time-serial data (e.g., electrical power, current, voltage; mechanical vibration and torque; stress and strain) and provides the equipment health status in a "traffic-signal-inspired mode:" green for "go" (nominal operation), yellow "caution" (forewarning of failure), and red for "stop" (immediate shutdown to avoid failure). The analysis is much faster than real-time, and can handle multiple data streams for prognostication at the component level. 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 – Ongoing 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 field testing) involve primarily: (i) extensive statistical validation for specific equipment fault(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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