Wavelet-Based Real-Time Diagnosis of Complex Systems

Changes in hardware and software can be simultaneously examined for signs of loss of control.

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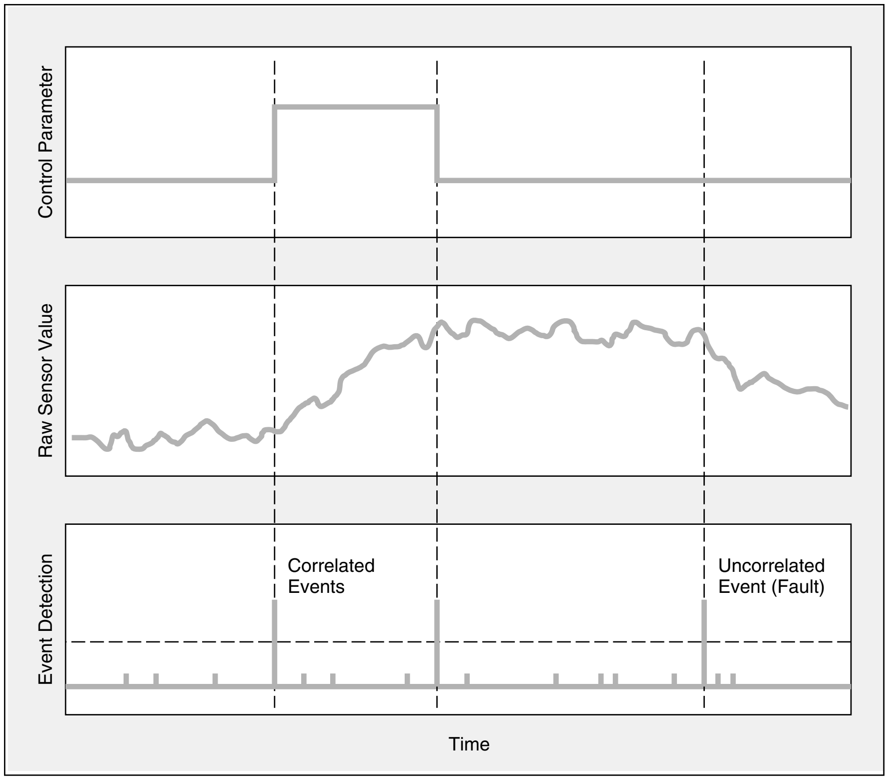
A new method of robust, autonomous real-time diagnosis of a time-varying complex system (e.g., a spacecraft, an advanced aircraft, or a process-control system) is presented here. It is based upon the characterization and comparison of (1) the execution of software, as reported by discrete data, and (2) data from sensors that monitor the physical state of the system, such as performance sensors or similar quantitative time-varying measurements. By taking account of the relationship between execution of, and the responses to, software commands, this method satisfies a key requirement for robust autonomous diagnosis, namely, ensuring that control is maintained and followed.

Such monitoring of control software requires that estimates of the state of the system, as represented within the control software itself, are representative of the physical behavior of the system. In this method, data from sensors and discrete command data are analyzed simultaneously and compared to determine their correlation. If the sensed physical state of the system differs from the software estimate (see figure) or if the system fails to perform a transition as commanded by software, or such a transition occurs without the associated command, the system has experienced a control fault. This method provides a means of detecting such divergent behavior and automatically generating an appropriate warning.

The method is general enough to detect changes in a variety of systems, characterized by cycle times ranging from milliseconds to months or beyond. Detection of changes is accomplished using a wavelet decomposition, which is scalable to arbitrary temporal characteristics and sensitive to changes in any derivative. Wavelet decomposition itself is computationally efficient and is widely used in signal conditioning and image compression. Our method applies a similar approach to time-varying signals and performs an extraction and characterization of significant events, which serves as detector and classifier of commanded responses and anomalies based upon their temporal and spatial characteristics. This method is fundamentally superior to traditional fault monitoring, which relies upon thresholds set upon absolute sensor data, derivatives, and the like. The wavelet filter also offers the advantage of adaptability to nearly any signal.



In this **Simple Example,** events detected from a paired control signal and sensor signal are initially temporally correlated, but they do not show correlation as expected. The uncorrelated event is detected by this method and signifies the occurrence of a fault.

The method is implemented by applying the scalable algorithm directly to raw or preconditioned signal data. The algorithm resolves generic transitions and characterizes them in a low-order dimensional representation, according to the scaling and perfect-reconstruction capabilities of the wavelet decomposition. This algorithm is applied alongside a logical difference operator acting upon preselected discrete data signal representative of software control. Selection of these signal pairs can be performed manually using expert knowledge, or through other elements of BEAM (Beacon-Based Exception Analysis for Multimissions), which is described in "Software for Autonomous Diagnosis of Complex Systems" (NPO-20827), *NASA Tech Briefs*, Vol. 26, No. 9 (September 2002), page 32. Events in the two streams are detected and compared according to temporal index, confirming consistent system/software execution or revealing the presence of anomalous behavior.

The final output of the algorithm includes a simple flag indicating nominal or faulty operation. Information on the time of fault onset and parameters characterizing the fault are also provided. Such information can be directed to the system control or further analyzed as part of the complete BEAM framework. This method is sensitive to both hard failures and incipient faults, including degradation and sensor failure, in addition to monitoring control and response.

This work was done by Sandeep Gulati and Ryan Mackey of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com****.*
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