integration. Examples of off-core activities are management of risk and opportunity, verification, validation, and troubleshooting. Because these activities are usually repeated many times and may not inherently be ordered in the same way as the core processes, they often cannot be represented by use of simple graphical aids. The complexity and difficulty of the task of representing off-core activities is increased by the fact that the timing and type of work involved in these activities are more unpredictable than are those of core activities.

In the present methodology, as applied to the development of a given system, the systems-engineering plan is organized to explicitly treat core and off-core activities separately. This approach to organization provides a conceptual framework that can facilitate and accelerate understanding, by members of the systems-engineering staff, of the relationships among many parallel activities. In so doing, this approach can reduce the difficulty of coordinating those activities.

This work was done by Julian C. Breidenthal of Caltech and Kevin Forsberg of the Center for Systems Management for NASA's Jet Propulsion Laboratory. For more information, contact Julian Breidenthal at julian.breidenthal@jpl.nasa.gov. NPO-45745

Digital Reconstruction Supporting Investigation of Mishaps

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In support of investigations of mishaps like the crash of the space shuttle *Columbia*, a process based on digital reconstruction from recovered components has been developed. The process is expected to reduce the need for physical reconstruction from recovered parts, reduce the time and cost of determining the cause of a mishap, and provide information useful in redesigning to prevent future mishaps.

The process involves utilization of pre-existing techniques, hardware, and software to capture sizes and shapes of recovered parts in sets of digital data. The data are manipulated to enable rendering of captured geometric information by use of computer-aided design (CAD) and viewing software. The digitization of a part and study of its spatial relationship with other parts is taken to one of three levels of successively greater detail, depending on its importance to the investigation. The process includes a trajectory-analysis subprocess in which information from the digital reconstruction is combined with locations of recovered parts to reduce the area that must be searched to find other specified parts that have not yet been recovered. The digital product of the process is compatible with pre-existing CAD and solid-model-rendering software.

This work was done by William D. Macy and Robert B. Luecking of The Boeing Co. for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)}, to The Boeing Co. Inquiries concerning licenses for its commercial development should be addressed to:

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Refer to MSC-23783-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Template Matching Approach to Signal Prediction

An improvement is made in accurate prediction of future behavior and early detection of system problems.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new approach to signal prediction and prognostic assessment of spacecraft health resolves an inherent difficulty in fusing sensor data with simulated data. This technique builds upon previous work that demonstrated the importance of physics-based transient models to accurate prediction of signal dynamics and system performance. While models can greatly improve predictive accuracy, they are difficult to apply in general because of variations in model type, accuracy, or intended purpose. However, virtually any flight project will have at least some modeling capability at its disposal, whether a full-blown simulation, partial physics models, dynamic look-up tables, a brassboard analogue system, or simple hand-driven calculation by a team of experts.

Many models can be used to develop a "predict," or an estimate of the next day's or next cycle's behavior, which is typically used for planning purposes. The fidelity of a predict varies from one project to another, depending on the complexity of the simulation (i.e. linearized or full differential equations) and the level of detail in anticipated system operation, but typically any predict cannot be adapted to changing conditions or adjusted spacecraft command execution. Applying a predict blindly, without adapting the predict to current conditions, produces mixed results at best, primarily due to mismatches between assumed execution of spacecraft activities and actual times of execution. This results in the predict becoming useless during periods of complicated behavior, exactly when the predict would be most valuable. Each spacecraft operation tends to show up as a transient in the data, and if the transients are misaligned, using the predict can actually harm forecasting performance.

To address this problem, the approach here expresses the predict in terms of a baseline function superposed with one or more transient functions. These transients serve as signal templates, which can be relocated in time and space against the signal background. One then has the ability to reconstruct a signal regardless of the precise timing of the transients. During operation, one applies the actual start times of spacecraft activities as they occur, and produces a reconstructed, accurate predict in real-time.

This general approach is valid under two important conditions. First, the transients themselves must be time-invariant. Second, the transients must be reasonably consistent with respect to different operating points. Both of these assumptions are generally valid, but in the case of a complicated system with numerous types of overlapping transients, this approach may not be effective. Fortunately, there tend to be few transients in spacecraft telemetry of sensor quantities or low-level health and status information because these signals rarely reflect multiple different types of operation. Furthermore, if the predict is at least reasonably close to actual operation, the shift — either in time, or in the operating point when the transient occurs — is likely to be small.

The proposed approach considers three ways to recognize a transient. The first and most reliable is to use a different signal that identifies operating mode — often the transient will be correlated to a change in operating mode, and this change can usually be detected positively from discrete signals in spacecraft telemetry. If there is no useful mode signal, the second option is to identify the transient template by hand, and detect the onset of the transient using a curve-fitting approach. Finally, if one elects not to choose by hand, there is an option for automatic selection.

This technique has been applied to sensor data from several JPL missions and industrial applications, demonstrating an improvement in accurate prediction of future behavior and early detection of system problems. This technique is applicable to practically any time-varying, quantitative sensor measurement.

This work was done by Igor K. Kulikov and Ryan M. Mackey of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). ***NPO-47159***