ORBITAL SIGNATURE ANALYZER (OSA): A SPACECRAFT HEALTH/SAFETY MONITORING AND ANALYSIS TOOL

Steven Weaver, Charles DeGeorges, and Joy Bush
Computer Sciences Corporation
1100 West Street, Laurel, MD 20707, USA

N94-23947

Robert Shendock
TRW, Incorporated
One Space Park, Redondo Beach, CA 90278, USA

Daniel Mandl
NASA/Goddard Space Flight Center
Code 511.2
Greenbelt, MD 20771, USA

ABSTRACT

Fixed or static limit sensing is employed in control centers to ensure that spacecraft parameters remain within a nominal range. However, many critical parameters, such as power system telemetry, are time-varying and, as such, their "nominal" range is necessarily time-varying as well.

Predicted data, manual limits checking, and widened limit-checking ranges are often employed in an attempt to monitor these parameters without generating excessive limits violations. Generating predicted data and manual limits checking are both resource intensive, while broadening limit ranges for time-varying parameters is clearly inadequate to detect all but catastrophic problems.

OSA provides a low-cost solution by using analytically selected data as a reference upon which to base its limits. These limits are always defined relative to the time-varying reference data, rather than as fixed upper and lower limits. In effect, OSA provides individual limits tailored to each value throughout all the data. A side benefit of using relative limits is that they automatically adjust to new reference data. In addition, OSA provides a wealth of analytical by-products in its execution.

Key Words: Orbital signature, limit sensing, telemetry, spacecraft

1. INTRODUCTION

The responsibility of the control center is to maintain the health and safety of the spacecraft. Controllers utilizing traditional tools routinely perform a real-time rudimentary state of health assessment. This assessment is only as good as the available tools, analytical quality of the databases they access and the controllers that use them. Early detection and response to potential problems increases the probability of meeting mission objectives.

Traditional tools are limited and resource intensive. Only limit sensing provides a broad continuous assessment of spacecraft condition on the ground. While accurate assessment of bi-level states and slightly varying analog parameters can be achieved, tight limit definitions are required. Frequent database updates supported by intensive data analysis is needed to maintain the limits. Assuming this can be routinely supported, accurate assessment of widely varying parameters is seldom achieved. An example of a parameter in this class would be solar array current for a low earth orbiter. Despite the fact that the parameter is well behaved and shows a distinctive orbital character, steps are taken to avoid frequent erroneous limit violations. This is usually done by setting very wide general limits, then applying techniques (i.e., conditional limits, etc.) to better evaluate the slightly varying segments of the data. This process often results in some invalid limit violations and loose evaluation of the parameter over much of the orbit.

Despite best efforts, the probability of early problem detection is not what it should be. To compensate, additional engineering analysis is performed to supplement the real-time evaluation. The analysis is done to detect potential problems and assess system performance. Short, medium and long term trends are evaluated against a reference or the expected. Unfortunately,lag times and resource requirements are high in generating the analysis and transferring analytical products to the control center.

2. OSA CAPABILITIES

OSA was developed to solve these problems using an approach as old as control centers themselves. Traditional evaluation often involved a technique called "holding two overlapping plots up to the light". This produced a qualitative analysis not directly storable on magnetic media. OSA takes a more integrated and exact approach. The system performs a quantitative analysis of current versus reference data in real-time or batch modes. The reference data is analytically determined and may come from any source (i.e., simulator, s/c tape dump, etc.). OSA graphically displays reference data, current data and user defined variable limits on a single plot. More importantly, differences between the current and reference data are calculated and plotted with user defined difference limits. Limit sensing is performed on the difference data, violations are reported to the controller in real-time and violation statistics are maintained. The process significantly increases the control center's ability to accurately assess widely varying telemetry. This is accomplished by sensing against an analytically determined varying limit definition.

OSA is used to set new limit definitions upon user request. The reference data is graphically displayed and the user is allowed to segment the data. High and low limits are defined for each segment relative to the reference data values. Two types of limits can be defined. The most frequently selected is a percentage of each individual reference value. The other option is to apply a fixed offset to each reference point. Limit values are usually reviewed upon update of the reference image.

OSA allows the user full management of the reference image. Typically, candidate reference data is analyzed by OSA and optionally used to update the reference image upon engineer approval. Limit definitions can be modified. Limit values automatically adjust to the new reference data. The reference image and limit definitions directly reflect the current engineering requirements. Thus, detailed analysis can efficiently be transferred to the Control Center for real-time use in a painless manner.

3. OSA BENEFITS

One indicator of a tool's worth is the amount of unexpected benefit that falls out from its use. While detecting several problems and identifying other curiosities, OSA output supports most GRO documentation concerning the power subsystem where detailed analysis of orbital behavior is required. The OSA archival function has been used extensively to compare selected sets of data separated in time but collected under similar spacecraft conditions. In addition OSA contributes to medium and long term statistical data calculation.

The traditional statistics are calculated for the current data and include minimum, maximum, mean, standard deviation and variance. Uniquely, statistics are calculated for the difference data and include average differences, number of samples out of tolerance and the maximum number of consecutive samples out of tolerance. Statistical values for all parameters under evaluation are displayed on Statistical Summary Pages. These pages are routinely maintained during a contact in the real-time environment. Limit violations are indicated on these pages via a color coding scheme. The graphical displays are available and contain the statistics for the plotted parameter. All statistical data is available in standard format via magnetic media for subsequent analysis.

OSA has proven itself by the early detection and detailed analysis of the GRO (Gamma Ray Observatory) MPS-1 battery problems. While two missions were experiencing similar problems, GRO was able to clearly identify the problem early on and define even slight character changes in battery state of health indicators. To this date, GRO still provides the most detailed data analysis of early battery degradation character. This, of course, is important to the future. OSA's capabilities are required for the earliest detection of problem symptoms.

The control center's experience with OSA has been very rewarding. This is due to the soundness of the concept, the quality of the products and the professionalism of the developers.

4. OSA IMPLEMENTATION

At start up, OSA menu options allow the FOT to provide default settings for manual or automatic ("sleep mode") analysis and print operations. During operation, OSA settings, display ranges, manual or sleep mode operation, and navigation among mnemonics are controlled through function keys.

The PC version of OSA uses C along with an assembly language-based commercial graphics package to immediately display or modify graphical elements such as orbital signatures, associated tolerances, moveable timelines, or tolerance band boundaries, even on a 286-based PC. Display ranges for parameters may be modified, and the current data may be manually aligned with the reference to further refine the automatic alignment performed to eliminate the effects of nodal precession on the current data.

The TPOCC (Transportable Payload Operations Control Center) version of OSA is being developed for Hewlett Packard and Sun workstations in C++, using OSF/MOTIF, and is X-Window based.

5. OSA EVOLUTION AND FUTURE DIRECTIONS

OSA is intended to be a real-time telemetry monitoring tool for time-varying parameters such as power system data for the GRO. OSA was to use neural networks trained on orbital signature examples that indicated developing problems. In this way, OSA could examine either tape recorder playback or real-time pass data and flag impending problems BEFORE they exceeded critical limits. The neural networks were to be trained on simulated or hand-estimated data generated before launch. Thus the origin of the currently used acronym of OSA in the GRO - ESP expert system predictor (as shown on Figure 1).

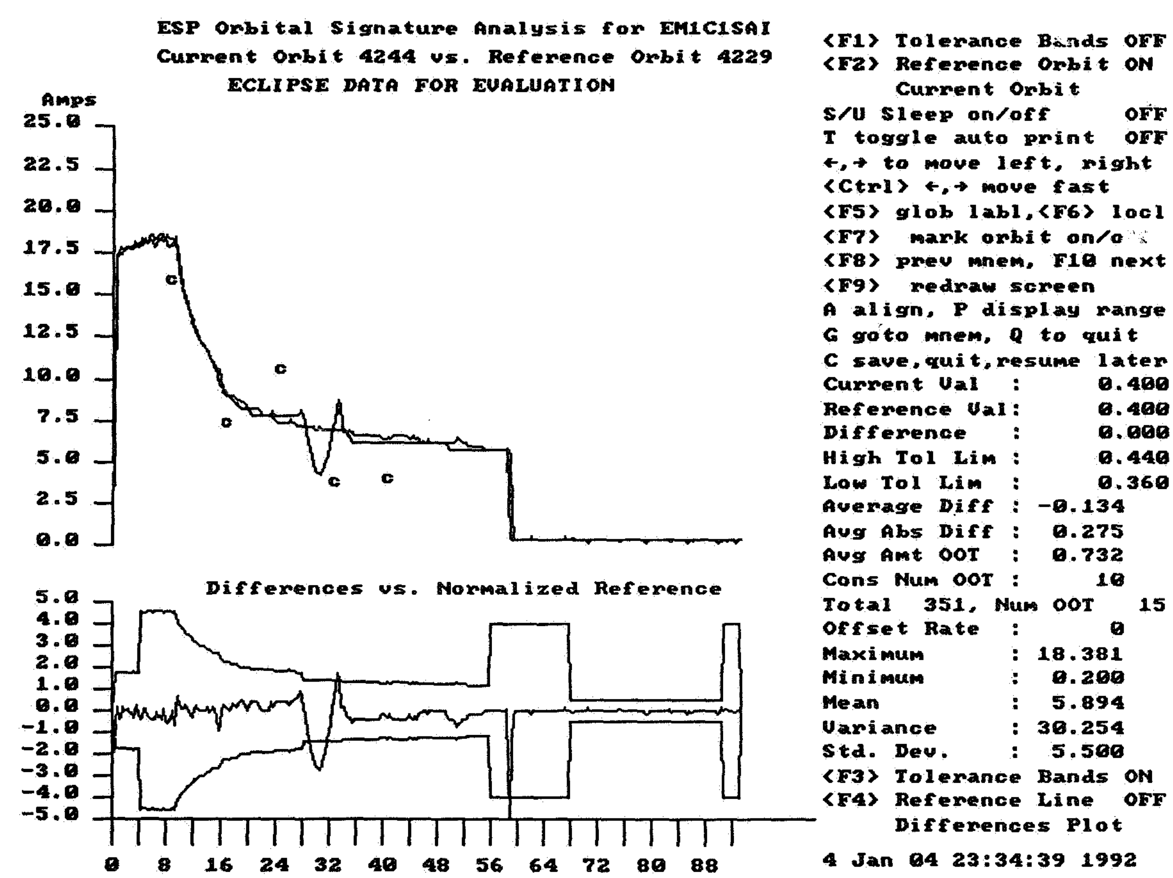

Figure 1. OSA Plot of GRO Solar Array Current Eclipsed By The Sun

Five key lessons learned are shown below that describe both the development process as well as the user (and non-user) reaction to OSA.

LESSON 1 - *A model-based system needs a model*

Simulators are wonderful tools, but for many missions and for a variety of reasons, simulators are not able to supply the necessary training data for the neural networks. For the GRO, the spacecraft analyst felt that the predicted power system values, while reasonable, were not sufficiently certain to be used as the basis for neural network training. However, the concept of a reference orbit, as a basis for comparing current data, was kept.

As delivered, OSA uses a previously captured (and reviewed and approved) orbit's data as a reference for comparison to the current. Operationally, the reference for the GRO is updated daily using the daily orbital data after comparison to the previous reference orbit. This works well in practice because day-to-day orbital signature variations are small. Ultimately, OSA will still use neural networks trained on flight data along with auxiliary information to recognize developing problems on-board the spacecraft, thus living up to its name, ESP.

LESSON 2 - *Prototype, demonstrate, and change - continually*

From the developer's perspective, OSA is a success story due in part to excellent customer feedback from the many prototype demonstrations performed, but also due to constant incorporation of changes or new features. No feature, tool, or approach was held sacred except the final objective of the system itself. Changes were so extensive that the completed offline PC-based version of OSA incorporated neither neural networks nor used simulator data as originally planned but, most importantly, it met the user's data monitoring and analysis needs.

LESSON 3 - *For analysts, quantity is more important than quality*

Analysts make critical spacecraft operational decisions based on the data supplied by various tools. They will make use of qualitative assessments if they are given the numbers as well. If only one of the two can be provided, they want the numbers instead of the tool's "expert" assessment of what is happening on-board the spacecraft.

OSA/ESP is trusted because it provides analyst-selected quantitative measures of the spacecraft power system state of health based on analyst-assigned tolerances employing an analyst-approved reference orbit.

LESSON 4 - *The FOT may dislike what the spacecraft analyst loves*

The flight operations team and spacecraft analysts have different needs. The FOT user desires automation of routine activities that include data capture, comparison, analysis, and plotting, and print and archive. FOT interaction is desired only when exceptions are reported that highlight potential problems. To that end, saved menu selections, predicted event file inputs, statistical summary pages and color coded limit sensing are provided by OSA. OSA automatically displays and prints statistics as well as plots.

The spacecraft analyst, on the other hand, may wish to investigate specific problems, such as out-of-tolerance conditions, spotted by the FOT. OSA manual navigation features include moving among mnemonics, displaying a specific mnemonic, save and resume capability, select and set tolerance bands and values, modifying display ranges, tolerance thresholds, manually aligning current and reference orbit signatures, and switching on or off any of the automated functions.

We learned that, if in doubt about which features to provide to the typical spacecraft analyst, at a minimum, do the following:

- Capture and plot everything
- Compute all statistics
- Archive and print everything
- Process previously archived data
- Output data and statistics in "standard" formats, ASCII, and format for "standard" reports as well
- Allow any or all of these features to be toggled on or off
- Allow saving of feature settings

- Allow for batching or grouping of various menu commands to permit hands-off (a.k.a. "sleep mode") operation

- Anything else thought of during the prototyping and testing process

On the other hand, for the FOT, the rules are simple. For a tool fated for control center use ensure that the tool does the following:

- Does not require frequent tending

- Output is reliably correct

- Return exceeds the effort

LESSON 5 - *The OSA concept is too simple to understand.*

We've demonstrated OSA dozens of times both to those with control center experience (both FOT members and spacecraft analysts), and to those with less familiarity with spacecraft operations. Because OSA also happens to plot orbital data and generate statistics, it is often mistaken for a trending and/or plotting package. These and other common reactions are listed below followed by a summary of our typical response.

- Doesn't standard limit checking do this checking already? *No, it essentially just performs catastrophic limit checking for time varying parameters.*

- An OSA out of tolerance condition does not indicate a problem if the value is still within the static limits. *It most certainly does (we cite the GRO battery and the GRO lunar eclipse example).*

- We already have a plotting and/or a trending package.

- We already plot out all data for critical parameters.

- We already generate standard statistics for all parameters.

- We already look at the plots of problem parameters.

  Rarely, if ever, are the four items above done in a single package either in real-time or in background. They are by-products of OSA, not the product.

- We don't really need OSA because the only thing that it has that our tools currently do not is this idea of a reference. *You still don't routinely (daily and each pass) align and compare all critical parameters to their respective references and produce a quantitative assessment.*

- Isn't there too much change in the orbital signature daily? *No, while the daily change is a fraction of each time-varying parameter's static limit range, future enhancements will analytically verify changes in spacecraft profile allowing OSA to expertly adjust tolerances.*

- OSA runs on a PC and will soon run on Sun and HP workstations. Could we use it in our control center without many/any changes ? *Quite possibly.*

6. ENHANCEMENTS UNDERWAY

Present enhancements currently under development include an expert system to modify the reference curve and current orbit data according to the operational state of the spacecraft, thereby accounting for the effect of spacecraft activities during curve comparison. Closer alignment of the two curves permits even tighter tolerances to be assigned. The state change rules are user definable. The reference orbits may be hand modified using mouse input. Also, patterns of interest may be identified using the mouse and searched for by neural networks trained on the patterns.

Finally, the system is being integrated into a new NASA/Goddard TPOCC, and will be object oriented and Motif compliant, for use on such missions as SAMPEX and Wind/Polar.