An Interactive Visualization System for Analyzing Spacecraft Telemetry[1][2]

George Cancro, Russell Turner, Lilian Nguyen, Angela Li, Deane Sibol,
John Gersh, Christine Piatko, Jaime Montemayor, Priscilla McKerracher
Johns Hopkins University – Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723-6099
{George.Cancro, Russell.Turner, Lilian.Nguyen, Angela.Li, Deane.Sibol, John.Gersh, Christine.Piatko, Jaime.Montemayor, Priscilla.McKerracher}@jhuapl.edu

Abstract—Traditionally, the diagnosis of spacecraft anomalies during test and flight is slow and not very thorough due to a limited view of telemetry. The process is an off-line, linear analysis of guessing a root cause and then attempting to verify the guess through identifying and plotting telemetry channels over the appropriate time period. The desire of mission operators and testers is to have a capability to analyze all telemetry channels simultaneously and then be able to freely move through time to cover the entire problem space. Current telemetry display systems, however, only allow an operator to examine on the order of 100 telemetry channels simultaneously from a real-time stream, through a rudimentary playback, or step control of a telemetry archive. This limitation increases the risk that anomalies will be missed and increases the time to determine the real root-cause of the problem. This paper discusses the development and implementation of a visualization system that facilitates a thorough review by enabling an operator to analyze all telemetry data by pattern. This system, called the STEREO Autonomy Visualizer (SAV) also enables the rapid review of data by using a 'real-time random access' method for viewing real-time and archive telemetry streams. By using the system, STEREO testers have identified bugs that other test review techniques have missed, and decreased the time necessary to perform test review by more than a factor of 5. In addition, use of this system has resulted in a greater understanding of the spacecraft through the visualization of inter-relationships between telemetry channels during faults in flight.

TABLE OF CONTENTS

1. INTRODUCTION

The operation and system testing of spacecraft produce a large amount of data. For example, the APL STEREO spacecraft [19] produces at least 3000 different specific telemetry channels per second. Therefore, during a typical 8 hour shift, over 86 million telemetry values are generated and stored for review and analysis. However, as with many other spacecraft missions, the majority of the data is never reviewed due to time constraints and manpower issues.

Current spaceflight practices for analysis of test or flight data is mainly a process of trial and error. The analyst must select a telemetry channel to examine, plot the data over a given time span using standard data plotting software tools, and then determine if this plot provides the information sufficient to confirm a hypothesis. If the information is insufficient, the process is repeated as necessary. As a result, the analysis is usually neither thorough nor complete, and there is a large potential that the analyst will miss the root cause of a problem. Since there is no ability to visualize all the data channels simultaneously along with their interactions, the interrelationships that are explored using current practice tend to be analyst-dependent, and rely on the separate knowledge bases of each person.

For real-time monitoring of testing and flight operations, an operator typically views a screen that displays real-time values of telemetry channels of interest. Displayed either as numbers or schematic mimic diagrams, the maximum number of channels that can be viewed simultaneously is usually on the order of 100. In addition, there is no capability to review recent history data in a real-time stream. If an event or problem is missed, the operator is required to perform an off-line analysis. This approach prolongs the response time to a problem and may impact scheduled spacecraft operations.

1———————————

[1] 1-4244-0525-4/07/$20.00 ©2007 IEEE
[2] IEEEAC paper #1203, Version 5, Updated January 2, 2007

Our goal in designing a modern telemetry visualization system is to increase an operator's awareness of all telemetry channels over time within a single display in order to facilitate both focused and comparative analysis of data collected in real-time and from historical archives.

In this paper, we describe a new interactive visualization system we have developed, which combines visualization techniques such as dense color-based displays and interactive timelines to provide a solution to these goals. We present an overview of the visualization and interaction capabilities of the system, an example of how the system is used on NASA's STEREO mission, and an analysis of the effect of this system on the STEREO test program.

2. RELATED WORK

A number of authors have described visualization techniques specifically for spacecraft telemetry data, but they tend to be oriented towards scientific data [17],[18],[6]. Most current telemetry visualization systems make use of visualization techniques falling into two categories: mimic-diagrams and time-series diagrams. Commercial visualization systems employ both techniques.

Telemetry Display

Mimic Diagrams—Mimic diagrams are animated schematic displays which represent the current state of a hardware system using icons, drawings of the real-world entities they represent, or physical dials and meters. General purpose, commercial user interface builder products such as DataViews [9], LabView [7], and SAMMI [13] have been used since the mid 1980's to build specialized mimic diagrams that animate in response to real-time data sources.

Time-series Visualization—Time-series diagrams predate the computer graphics age by several centuries [14]. The invention of the strip-chart recorder and oscilloscopes made possible the real-time display of continuous time-series data, and early computer displays of time-series data were modeled after them. The development of the MIDI [8] standard in the '80s sparked a variety of computer based visualization and editing tools for musical instrument event data.

A large body of research exists in the field of time-series data visualization [4], [7], [2], [15], [11] and many innovative techniques continue to be developed. For example Weber [16], uses spirals to visualize periodic behavior, and LifeLines [10] uses a timeline overview to provide access to personal history data allowing focus plus details in context.

Commercial Telemetry Analysis Systems

EPOCH, used by APL for STEREO and other spacecraft, is a good example of a commercial system for spacecraft ground system monitoring and control [3]. While EPOCH provides the ability to create specialized mimic-diagram and time-series displays for specific telemetry channels, these are impractical for displaying more than a few dozen data channels at the same time.

EPOCH also provides the capability to track telemetry alarms through its Alarm Management Tool, track spacecraft events through the EPOCH Event Viewer, and perform offline analysis and reporting of historical telemetry data using it's Archive Browser and Extractor tool. These functions are practical to ground operators as a method of reducing the number of data channels to monitor by using separate text displays and different coloring to indicate the most essential data. Maintaining context among alarms, events and data, however, is difficult since the operator must negotiate several different windows to understand what has happened. In addition, these functions are only pointers to potential problems, and the burden still falls on the operator to go off-line and re-locate the past problems with separate displays, thereby sacrificing the view of current data.

ITOS [5], RIMS [12], and AceTWS [1] are other examples of commercial products that visualize telemetry using data displays, mimic diagrams, and data plots. For example, ITOS has the ability to display telemetry in pages, x-y plots, strip charts, sequential prints, and configuration monitors. RIMS can display up to 60 telemetry channels per page in a text based format and can display mimic diagrams or plots in other displays over the web. As with EPOCH, the main view of these tools consists of an alphanumeric display in which data values can be shown in engineering units along with other information such as units and a telemetry channel description.

During our research of existing systems, we noted the preference of operational staff for viewing time-series data as well as being able to visualize as many current-time engineering data values as possible simultaneously. While well-designed mimic-diagrams provided an intuitive representation of the current state of major engineering systems, their high screen real-estate requirements make them impractical for visualizing more than a few dozen telemetry values on the screen simultaneously. For displaying time history data, standard strip-chart displays take up similarly high amounts of screen space.

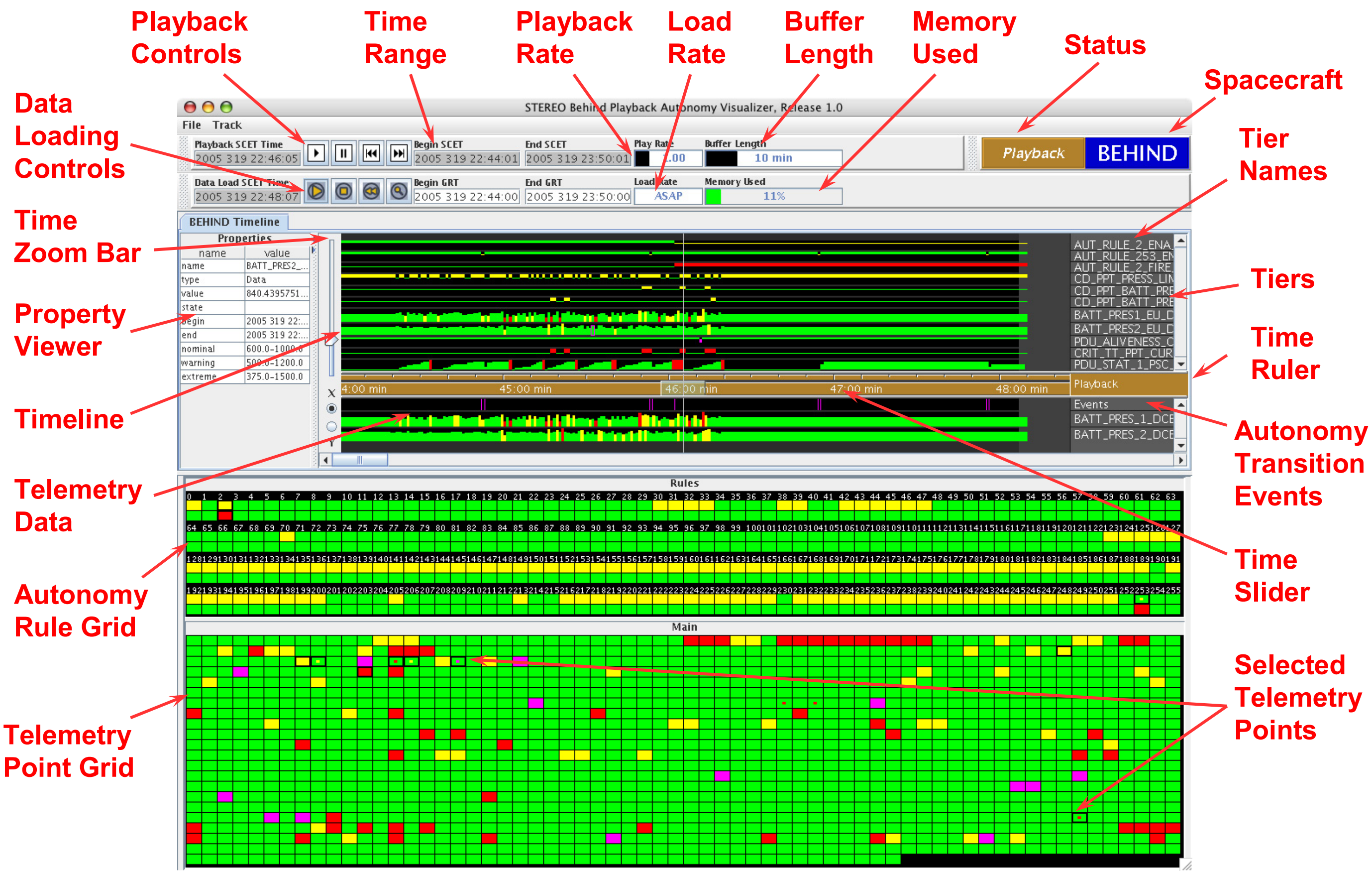


Figure 1: SAV user interface overview

3. SAV Concept

The STEREO Autonomy Visualizer (SAV) concept was developed to address the problems of off-line, linear analysis of archived telemetry data and to increase an operator's awareness of all of the telemetry data history over time. The result of this development is a new telemetry visualization tool that provides a thorough telemetry overview by allowing an operator to analyze all telemetry data by pattern. This system also allows the rapid review of data by using a 'real-time random access' method for viewing real-time and archive telemetry streams. These capabilities are achieved through the combination of an improved data access strategy covering real-time and archive data, dense grid views, and coordinated timeline views. These complementary views work in concert to provide enhanced context to operators.

The following sections discuss the data access strategy, the grid views and the timeline of this new system.

Accessing the Data

Two main types of data access are provided in SAV: real-time and archive. The same display is used for viewing current values of real-time data, playing back past values of the real-time data stream, or viewing static values at a user-selected past time. The current time of the data values displayed in the grid views is made explicit by a vertical hairline and time slider within the timeline view of the tool. The timeline view, in conjunction with the playback controls, allows the user to determine exactly what spacecraft event time (SCET) or ground receipt time (GRT) is being examined.

Irregardless of whether the user is viewing real-time or archive data, the time displayed can be driven either by the system or interactively manipulated by the user. This provides a unique capability to the user, allowing an operator to stop, reverse, play, or fast-forward time. The tool even provides random access to time, by allowing the user to manipulate the time slider in the timeline view.

SAV stores up to an hour's worth of data in a local memory buffer. When viewing archive data, the user can plot data trends over the loaded time interval of one or more telemetry channels by simply selecting the channels. This "thick client" architecture allows the user to rapidly switch between telemetry channels and view data at any time within the buffer range without returning to the archive. Instead of having standard plots, the user can perform comparative plot analysis of any combination of channels in real-time. When reading real-time telemetry data, the local memory buffer stores a history of received data. By using this history, a user can look back in the real-time data stream without affecting his ability to follow the current data. Unlike other telemetry tools, where a one-time event is immediately lost, SAV allows these events to be retrieved and then compared to other data over time, enabling the operator to quickly investigate event root causes without leaving the real-time telemetry display.

Grid Views

The grid views present a cross-sectional view of the telemetry data, displaying the state of all the spacecraft's data simultaneously at the time indicated by the time slider. Data channels are represented as small rectangles rendered using a limited palette of colors to represent normal and anomalous data values. This dramatically improves the density of information in a display, making it possible to display several thousand current-time data values, and several dozen time histories simultaneously on the same screen.

This arrangement of presenting all data values simultaneously enhances the ability of the human visual system to detect patterns in changing data values, allowing the user to discover previously unknown relationships among the telemetry channels. These cross-sectional views also foster the detection of patterns in the data that might indicate correlations among the data. To avoid the possibility of missing important information, the data grids do not contain overlapping windows or pop-up dialog boxes, which could obscure data. In addition, we attempt to minimize modal behavior as much as possible.

Only a small number of colors are required since spacecraft operators don't usually need to see exact values but rather need to be able to readily distinguish normal from anomalous values. Colors follow a standard traffic light metaphor, where green represents values within normal limits, while yellow and red represent values that are in the warning and danger ranges, respectively. Gray indicates that no data has been received on that channel, and magenta indicates values out of the range of the telemetry sensors and therefore presumed erroneous. Darker values of green, yellow, red, and purple indicate that the channel has received data in the past, but that it is "stale", or out-of-date.

The telemetry names and exact values associated with each square can be determined via mouse-over tool-tips as shown in Figure 2. Telemetry values that have a higher-level interpretation, such as a named state or a floating point number, are displayed in its highest form rather than the raw integer value. The combination of the dense grids with individual telemetry value tool-tips, allows an operator to view the entire data set and simultaneously investigate the details of telemetry channels of interest directly. If further investigation is required, the user can select that channel by clicking on its square within the grid, causing its time-history to appear in the timeline view.

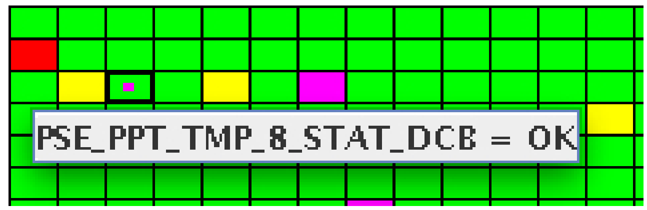


Figure 2: Grid View showing telemetry channel rectangles with various colors and mouse-over tool-tips.

Although the grid views basically display a slice of data at a given time, we developed two techniques to add some history information to the grid rectangles: historical limit violation and last value before stale. For historical limit violation, a small colored dot in the middle of the square indicates that the telemetry channel has violated a yellow, red or purple limit in the past. A grid rectangle that has a darker version of green, yellow, red or purple indicates the alarm state of the last telemetry point received prior to that telemetry channel going stale. These techniques enhance the operator's ability to work with large data grids, especially if the user had to leave the display and then return at a later time.

Telemetry channels can be organized into one or more grid views in any order within each view. Not much significance is attached to the relative location of data values within each grid view. They are positioned in sorted order by telemetry channel name, which gives them a rough organization by spacecraft subsystem and therefore by function, but the interactions, known and unknown, between the various telemetry channels is sufficiently complex that determining how best to visually represent these relationships is a separate research topic in itself.

The grid setup used for the STEREO autonomy visualizer is separated into two different grid views: the rule view and the main view. The rule view displays telemetry channels associated with the spacecraft on-board autonomy system including the enabled and firing state of all numbered autonomy rules. The main view displays all other telemetry channels that are associated with different types of autonomy. The separation of the grid into two views allows the autonomy team to give prominence to the workings of the autonomy system over other spacecraft subsystems and allows the autonomy team to give special properties to the autonomy grid view. The main special function provided was the modification of the 'select channel' feature. Within the main grid view, selecting a channel, by clicking on the telemetry channel square, adds the telemetry channel to the timeline view for time-history analysis. The same operation in the autonomy grid view not only adds the telemetry channel selected but also displays all of the telemetry channels associated with the particular rule. For example, if a star tracker autonomy rule executes, the grid rectangle associated with the telemetry state of that autonomy rule would turn red, indicating the execution. When the user selects the red rectangle, the telemetry history of the rule as well as all relevant star tracker telemetry channels appear on the timeline.

Timeline

The timeline view presents a longitudinal, time-history view of selected data channels, and consists of a time ruler surrounded by stacks of data tiers, each displaying the time history of its associated telemetry channel as a bar chart, as shown in Figure 3.

The timeline is divided into two areas: the user selectable area above the time ruler and the event area below the time ruler. The user selectable area consists of the time-history displays of all the telemetry channels that the user has selected from the grid views. Multiple telemetry channels may be selected to bring up their associated tracks in the timeline. The event area records the time of specific user-specified telemetry events as vertical lines at the time the event occurred. The event area therefore serves as a focal point for supporting the user's understanding of the context of the event. For the STEREO mission, each event in the tier represents a potentially spacecraft-threatening situation which the operator needs to know about. The type of event, distinguished by the color of the vertical line, represents which kind of situation the event is associated with. Clicking directly on the event in the timeline bring up its autonomy rule and associated telemetry channels in the timeline. This allows a user to quickly see an event and then produce the data needed to understand how that situation came about.

The bars for each telemetry channel time history are colored with the same color scheme as the grid view, so that anomalous data values are prominent. The order of the bar charts tiers can be interactively rearranged to group related data channels by dragging the channel's label up or down on the right-hand side. This allows the user to group related time-histories together to perform comparative analysis.

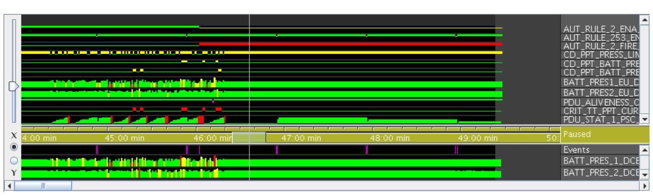


Figure 3: SAV timeline view showing multiple telemetry channels on multiple tiers.

The user can also inspect individual telemetry channel values in the timeline by selecting an individual bar, resulting in the display of more detailed information about the telemetry value at that specific time in a text box located to the left of the timeline called the Property View. This view contains a table-based view of the telemetry channel, displaying its raw value, its state or converted value, the red, yellow and purple alarm ranges for the channel, and the time interval over which the value was maintained. This feature allows the user to quickly determine minimums and maximums of telemetry channels and then get exact values and times of these extrema.

The timeline can be zoomed continuously in the horizontal dimension to change the displayed time interval and in the vertical dimension to change the height of the tiers. Zooming out in the horizontal dimension allows the user to see a birds-eye view over the time span. Zooming in to specific areas of the timeline allows investigation of individual telemetry data values. The timeline can be panned forward and backward in time at the current zoom level as well. Zooming in the vertical direction modifies the maximum height of the bar charts tiers. This height can be shrunk down to as little as one pixel, in which case only color information can be seen.

4. EXAMPLE OF USE

The section examines how the SAV tool was used during the launch of the STEREO spacecraft and demonstrates the breadth of information it can provide to the user.

Figure 4 shows the SAV tool at the time of launch. Nominally the grid views should be green showing all telemetry within limits and ready for launch. The yellow squares in the grid, however, reveal small deviations. Using the grid views, the user can easily see discrepancies and select them to appear in the timeline view for analysis of trends.

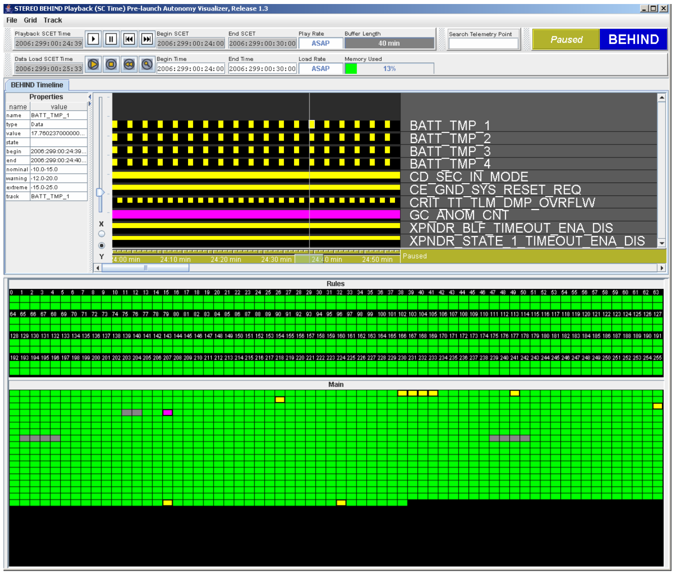


Figure 4: SAV screen shot at 14 minutes to liftoff.

Figure 5 shows the SAV timeline at the time of first contact with the satellites following launch. The spacecraft, still tumbling following tip-off from the rocket, waits for its scheduled detumble operation. The tumble is indicated by the spacecraft's angle to the sun, as measured by the spacecraft '*CE_MEAS_SUN_**' telemetry channels. Inspection of more grid points in the timeline view reveals that the measured location of the sun is different from the star tracker calculated location of the sun ('*CE_CALC_SUN_**') as shown in Figure 5. This is a first indication of a problem. As the user inspects more channels, he can determine that the attitude is not valid ('CE_ATT_VALID' is red) and the star tracker is not being used. The user can now begin to construct a hypothesis for the problem's root cause by examining and interactively displaying telemetry side-by-side for comparison.

Figure 5: SAV timeline at first contact showing the first symptoms of a problem in attitude knowledge

Figure 6 shows a heightened activity in the event area and autonomy grid as the spacecraft autonomously prepares itself for detumble operation. All of this activity is expected by operators except for the red squares in rules 62 and 63. The user clicks on the autonomy rule 62 square and all the relevant telemetry for that autonomy rule is displayed in the timeline. Inspection of the telemetry channel histories indicates that the star tracker was not in the correct state and that the on-board autonomy system is attempting to fix the problem. As the timeline shows, the autonomy system is able to promote the star tracker state ('ST_STAT') until the star tracker achieves a solution.

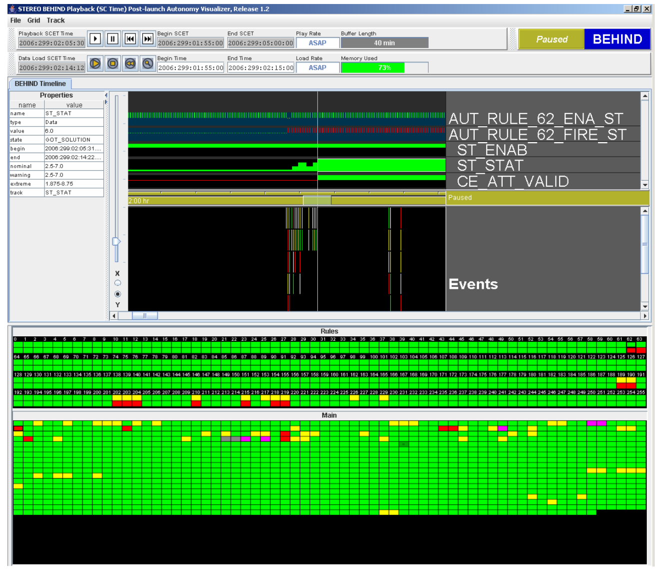


Figure 6: SAV screen shot after first contact before detumble showing on-board autonomy attempting to remedy the attitude knowledge problem.

Re-examining the measured and calculated sun position, in Figure 7, after the on-board fix, shows the attitude is now valid and a discontinuity is seen in the calculated sun position to now make it align with the measured sun. With 3-axis knowledge, the spacecraft completes the detumble operation successfully with the x-axis facing the sun (seen by X,Y,Z components of sun position turning green in timeline).

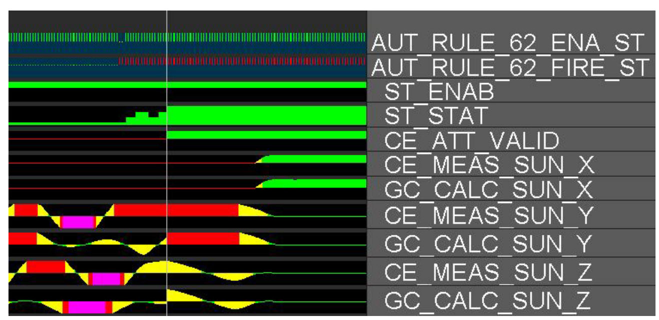


Figure 7: SAV timeline during detumble showing the remedy of problem and completion of detumble

5. RESULTS

The STEREO Autonomy Visualizer has been operational since February 2006 and was used by ground operators at APL during testing of the two STEREO spacecraft as well as launch in November 2006. During testing, SAV was utilized in two main roles: real-time test analysis and in post-test review.

The effect of real-time test analysis was difficult to quantify since the tool was used as a back-up to existing displays. Only when the test deviated from expectations did the operator switch to the SAV so that discovery of what actually did occur could be quickly understood. The effect of SAV in this role can be stated qualitatively in terms of improving on-schedule test successes even in the light of test deviations. Before the use of SAV in this role, tests that deviated outside the planned test bounds would be stopped and another test period would be scheduled several days in the future to allow for off-line analysis to be performed to better understand what happened prior to improving or re-running the test. With SAV, the operators could determine the cause of the deviation and repeat the test section during the original allocated test period.

The effect of post-test review can be quantitatively measured as a factor of 5 improvement based on the rate of tests reviewed shown in the test review burn down chart in Figure 8. Post-test review includes the evaluation of the as-run test procedure and archived data to independently prove that the test satisfied requirements and no deviations occurred. Before the use of SAV in this role on the STEREO program, the test review team completed 3.75 test reviews per month on average, based on the slope of the burn down prior to February 2006 (when SAV was introduced to the test review team). With SAV, the test review team completed 20 test reviews per month on average.

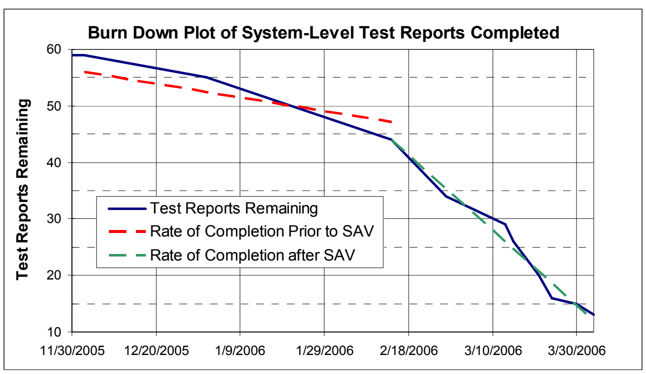


Figure 8: Burn down plot of test report completion on STEREO Program showing the speed improvement granted by SAV

6. FUTURE WORK

The ability to visualize large amounts of spacecraft information in a succinct display is highly desirable to support multi-spacecraft fleet operations with small operations teams. The SAV concept, especially when coupled with an ability to abstract telemetry information, may provide a unique capability to view abstract and detailed data of multiple spacecraft simultaneously in order to compare and contrast telemetry from each spacecraft. This may be accomplished by enhancing the SAV capability to handle multiple data streams simultaneously. Different data streams could be visualized in multiple timelines that can be randomly accessed separately to line up data trends over time, thus eliminating concerns of space and time variations over an entire constellation in differing orbits.

7. CONCLUSION

We have designed a highly interactive visualization system combining both a cross-sectional current-time view and a longitudinal timeline view of spacecraft telemetry data to enhance ground operators' ability to analyze and monitor spacecraft behavior during testing and flight operations. By presenting a view of all telemetry data channel values to the user simultaneously, while providing a mechanism to easily select specific channels to be displayed historically in a timeline view, we make it easier for the user to discover hidden dynamic relationships among autonomy behaviors and spacecraft telemetry data channels.

The system we describe is in operation, being used by autonomy system operators to monitor the health of NASA's STEREO mission spacecraft in flight. We are continuing to revise and update the software in response to user input.

8. REFERENCES

[1] Braxton Technologies Telemetry Workstation (AceTWS).http://www.braxtontech.com/a_telemetry_TWS.htm#01. Last Visited 12/1/06.

[2] John D. N. Dionisio and Alfonso F. Cardenas. Unified data model for representing multimedia, timeline, and simulation data. *Knowledge and Data Engineering*, 10(5):746–767, 1998.

[3] Integral Systems, Complete Satellite Ground System Solutions, Company Products (EPOCH). http://www.integ.com/Products.html. Last Visited 12/1/06.

[4] H. Hochheiser and B. Shneiderman. Dynamic query tools for time series data sets, timebox widgets for interactive exploration. *Information Visualization*, 3(1), March 2004.

[5] ITOS: A Satellite Control & Monitoring System. http://itos.gsfc.nasa.gov/. Last Visited 12/1/06.

[6] E. I. Koeberlein and S. E. Pender. Multimission Telemetry Visualization (MTV) system: A mission applications project from JPL's Multimedia Communications Laboratory. In *NASA.Goddard Space Flight Center, Third International Symposium on Space Mission Operations and Ground Data Systems, Part 1 p 233-240 (SEE N95-17179 04-17)*, pages 233–240, November 1994.

[7] "Is LabVIEW a general purpose programming language?" (website) http://zone.ni.com/devzone/cda/tut/p/id/5313. Last visited 12/1/06.

[8] "The Technology of MIDI" (website) http://www.midi.org/about-midi/abtmidi.shtml. Last visited 12/1/06.

[9] Alan Morse and George Reynolds. Overcoming current growth limits in UI development. *Commun. ACM*, 36(4):72–81, 1993.

[10] C. Plaisant, R. Mushlin, A. Snyder, J. Li, D. Heller, and B. Shneiderman. Lifelines: Using visualization to enhance navigation and analysis of patient records. In American Medical Informatic Association Annual Fall Symposium, Orlando, pages 76–80, Nov 1998.

[11] H Richter, J Brotherton, GD Abowd, and Truong K. A multi-scale timeline slider for stream visualization and control. *GVU Technical Report GIT-GVU-99-30*, 1999.

[12] RIMS: Remote Intelligent Monitoring System.http://www.interfacecontrol.com/products/RIMS/default.htm. Last Visited 12/1/06.

[13] "The Sammi® Application Development Kit" (website) http://www.kinesix.com/images/sammi_technical_description.pdf. Last visited 12/1/06.

[14] Edward R. Tufte. *The visual display of quantitative information.* Graphics Press, Cheshire, CT, USA, 1986.

[15] Patrick Stiegeler Wolfgang Huerst. User interfaces for browsing and navigation of continuous multimedia data. In *Proceedings of the 2nd Nordic Conference on Human-Computer Interaction, NordiCHI 2002,Aarhus, Denmark*, October 2002.

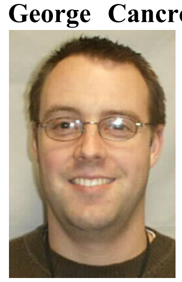
[16] Marc Weber, Marc Alexa, and Wolfgang Muller. Visualizing timeseries on spirals. In Proceedings of the IEEE InfoVis Symposium, pages 7–14, 2001.

[17] John Wright, Scott Burleigh, Makoto Maruya, Scott Maxwell, and Rene Pischel. Visualization experiences and issues in deep space exploration. In *VIS '03: Proceedings of the 14th IEEE Visualization 2003 (VIS'03)*, page 117, Washington, DC, USA, 2003. IEEE Computer Society.

[18] S. Zimmermann. Requirements of a long term telemetry data analysis and visualization tool for space missions. In *54th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law, Bremen*, Sep 2003.

[19] Mueller, J.T., Maldonado, H., and Driesman, A.S., "STEREO: The Challenges", 53rd International Astronautical Congress, The World Space Congress - 2002, Houston, TX, Oct 2002.

9. BIOGRAPHY



George Cancro is the section supervisor of the Fault Protection and Autonomy Section of System Engineering Group at the Johns Hopkins Applied Physics Laboratory (APL). George is currently the Fault Protection Lead and Deputy System Engineer for the STEREO mission. While at APL, George has worked with the autonomy systems of the MESSENGER and New Horizons missions and is the chief designer of the STEREO autonomy system. Prior to APL, George worked as a system engineer at NASA's Jet Propulsion Lab on several space missions including Mars Global Surveyor, Europa Orbiter, and Dawn. George has a B.S. in Engineering Science from Penn State and a Masters in Astronautics from George Washington University.

Russell Turner is a Senior Computer Scientist at the Systems and Information Sciences group at the Johns Hopkins University Applied Physics Laboratory. His research interests include information visualization, object-oriented software design, and interactive 2D and 3D graphics. Before joining APL, he worked at Celera Genomics, where he was technical lead for development of the *Celera Genome Browser*, a tool used to visualize and annotate the human genome. He has Bachelor's and Master's degrees in Computer Science from the University of Massachusetts, Amherst, and a Ph.D. from the Swiss Federal Institute of Technology, Lausanne.

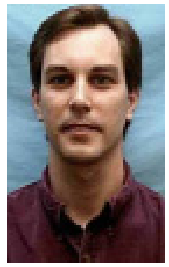
John Gersh is a Principal Staff Engineer in the System and Information Sciences Group at JHU/APL. His interests lie in the presentation of complex information for decision-making and in human interaction with automation. He has been involved in research and development in these areas for military command and control systems, space mission operations, intelligence analysis and other areas during his twenty-six years at JHU/APL. He has S.B., S.M., and E.E. degrees in Electrical Engineering from M.I.T.

Jaime Montemayor is a Senior Computer Scientist at the Systems and Information Sciences group at the Johns Hopkins University Applied Physics Laboratory. His research interests include human-computer interaction, design methodologies, information visualization, and ubiquitous computing. He received a B.S. in Civil Enginnering from the University of California, and an M.S. and Ph.D. in Computer Science from the University of Maryland.

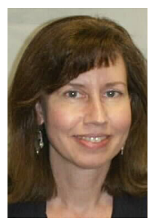
Angela Li is a Senior Professional Staff at the Ground Applications Group of Information System Branch in Space Department, Johns Hopkins University Applied Physics Laboratory. Before joining APL, she worked for Orbital Sciences Corporation's Transportation Management System Office as a Software Product Manager and several IT consulting firms, such as Commerce One and RWD Technologies. Her interests include web-based applications and database solutions for the enterprise. She has a BS degree in Physics from Fudan University, Shanghai, China and an MS degree in Physics from Texas A&M University, College Station, TX, USA.

Lillian Nguyen is a software engineer in the Science Applications group at the Johns Hopkins University Applied Physics Laboratory. Her work enables scientific data analysis for space missions and includes data visualization, image compression, and instrument pointing determination. She has a Bachelor's Degree in Mathematics from Indiana University and a Master's Degree in Mathematics from Johns Hopkins University.

Deane Sibol is a Senior Professional Staff member in the Ground Applications Group of the JHU/APL Space Department. He currently serves as the Common Ground Software Lead Engineer, overseeing the overall ground software architecture and directing the ground software development for four (4) NASA missions. He holds a BS in Computer Science from Loyola College, 1993, and a MS in Computer Science from Old Dominion University, 1995.



Priscilla McKerracher is a member of the Space Department Principal Staff at the Johns Hopkins University Applied Physics Laboratory. She is an experienced technical lead in software development for satellite systems. She has a Bachelor's degree in Physics, cum laude, Phi Beta Kappa, from the University of Illinois, Champaign-Urbana.



Christine Piatko is a Senior Computer Scientist with the Researchand Technology Development Center at the Johns Hopkins University Applied Physics Laboratory, and an Assistant Research Professor with the JHU Department of Computer Science. Prior to working at APL, she was a researcher for the National Institute of Standards and Technology. Her research interests include information visualization, computational geometry, machine learning, and human language technologies. She has a B.A. degree in Honors Computer Science and Mathematics from New York University and M.S. and Ph.D. degrees from Cornell University in Computer Science.