Analysis Of Satellite Telemetry Data

Lt Col Nancy L. Crowley, PhD, USAF
Mr. Vincent Apodaca, Nichols Research Corporation
USAF Phillips Laboratory, Space System Technologies Division (PL/VTS)
3550 Aberdeen Ave SE, Kirtland AFB, NM 87117-5776
phone: (505)846-0461, ext 313 or ext 318, fax: (505)846-6053
crowleyn@plk.af.mil, apodacav@maquis.plk.af.mil

Abstract—Satellites transmit data streams to the ground that consist of data values, called mnemonics, that are used to determine the health and location of the satellite. These data streams can contain between 700 and 12000 or more mnemonics. These mnemonics must be analyzed to ensure that the satellite is healthy, to assist in resolving any anomalies, and to determine if there are any trends that would indicate a possible future problem. Satellite engineers need assistance to assimilate and act on these large volumes of data.

The USAF Phillips Laboratory Space System Technologies Division (PL/VTS) has developed a telemetry analysis system called the Visual Interface for Satellite Telemetry Analysis (VISTA) that captures and displays satellite telemetry data in real time and provides tools for analyzing stored data.

An important aspect of VISTA is the analysis of stored telemetry data. The satellite engineer needs quick, accurate access to the stored satellite data in numerous forms, such as plots, reports, curve fitting, and Fourier analysis graphs. The challenge was to develop a telemetry analysis system that was flexible, fast, accurate, and able to provide the multiple views of the data required by the satellite engineers.

This paper provides an overview of VISTA, and then discusses how the telemetry analysis tool (TAT) was developed, how the system functions, timing information, and future work.

TABLE OF CONTENTS

1. INTRODUCTION

USAF Space Command has charged Phillips Laboratory with the task of reducing satellite ground operations costs while increasing the capability of the command and control system. The Space Systems Technology Division (PL/VTS) of Phillips Laboratory has responded to this charge by developing the Multimission Advanced Ground Intelligent Control (MAGIC) program. The MAGIC program addresses the cost issue by reducing the maintenance costs of the current hardware and software and by decreasing operational manpower costs. VTS has also developed the Visual Interface for Satellite Telemetry Analysis (VISTA) to address both the increased capability and low cost goals. The current USAF satellite command and control system has very limited support functions for the satellite operator and is very expensive to

0-7803-3741-7/97/$5.00

modify to meet new requirements. A new command and control system is being procured, but an interim system is needed until the new system is installed. This need was exacerbated by a sudden, drastic reduction in the number of skilled satellite engineers available during satellite contacts. USAF Space Command asked the USAF Phillips Laboratory Space System Technologies Division to develop this crucial interim solution. Since the MAGIC architecture was already under development, it was used as the basis for the development of VISTA. VISTA is currently being used in an operational room at USAF Space Command's Falcon Air Force Base.

VISTA stores all satellite data in processed form for the life of the satellite, displays the data real-time in graphical form, provides extensive analytical tools, provides system administrator tools to allow rapid database changes, and allows replays of data through the real-time screen. VISTA is built on the Windows NT operating system, and makes extensive use of commercial off-the-shelf components. For example, the telemetry data is stored in a commercial database that is hosted on a PC platform.

This paper focuses on the telemetry analysis tool (TAT) and its development. TAT provides the ability to view and print data from any recorded passes for any time period, including an ongoing pass. TAT can plot one pass or multiple passes across a particular time period. The data can be shown as it was recorded complete with gaps, or the plots can be extrapolated across the gaps. The system can print the data from a pass and can recreate and print the events for a pass. It also provides tools for curve fitting, Fourier analysis, and three-dimensional plots.

VISTA Overview

VISTA employs small components that each perform a single, isolated function, and that communicate by passing messages. The components in VISTA are: the real-time graphical user interface (GUI), the controller and distribution software, the front-end communication software, the relational database, the expert system, the telemetry analysis tool, the front-end software, and the administrative tool. The data is received from the satellite, decrypted, and sent to the front-end communication software. There engineering unit (EU) conversion is performed, and some derived values are calculated. Tuples of data consisting of mnemonic name, value, and time are sent to an operator workstation. The workstation calculates the remainder of the derived values, displays the data, and stores it in the relational database. The expert system generates events that the operators should acknowledge with some response. The telemetry analysis tool is used to analyze satellite data stored in the relational database.

The relational database, Microsoft SQL Server, stores all information received from the satellite, including derived parameters. Because of the low data rates for this application, the data is stored in processed form rather than raw form. This means the data is stored in EU-converted form, along with its start time, stop time, and color (if any). The colors represent whether the data is in its normal (green), caution (yellow), or alarm (red) range. A new row for a data point is created only upon change of the data's value. The database also stores satellite-unique information, isolating the changes that are required for new satellites or changes to existing satellites. These changes simply require modifications to database tables. The database provides the satellite-unique information to the workstations prior to a pass (a pass is a period of time when the data is being gathered from a satellite) for initialization and after the pass for data analysis.

2. Telemetry Analysis Initial Implementation -- Lessons Learned

The telemetry analysis system was initially developed using Microsoft Access and Visual Numerics PV-WAVE. Access was used to provide the user interface and gather the data from the relational database. Access gathered and formatted the data and called PV-WAVE through a dynamic data exchange (DDE) interface. PV-WAVE provided all plotting capabilities and Access generated all printed reports. There were a number of problems associated with the original design of TAT, such as speed and limitations using PV-WAVE.

The biggest problem with the initial TAT implementation was performance. For a 10 minute pass, approximately 80 thousand rows of data are recorded in the database. If the operator wanted to view satellite data for a mnemonic or mnemonics for a month, or even a week, the time to gather and process the data was too lengthy. There were also limitations using PV-WAVE through the DDE interface, and the original port of PV-WAVE to Windows NT did not provide the flexibility needed. For example, PV-WAVE graphics windows behaved as independent application windows rather than a part of the main TAT program. The curve fit routines were not accurate and could not determine if a straight line or polynomial fit was a better choice.

In a discussion with the satellite operators, they expressed the desire to have a separate database that contained summary data for their most commonly used mnemonics. Approximately 120 of these commonly used mnemonics were identified out of almost one thousand mnemonics for this particular satellite family. This would solve some of the problems with the time to gather the data for the summary database, since it would contain only a subset of the mnemonics and only one data point per mnemonic per pass.

An extensive analysis was conducted examining alternatives to the initial implementation, and timing tests were performed (see Table 1) using various methods of accessing data from the central database. By that time, Visual Numerics had updated their NT version of PV-WAVE, and an analysis was done on the updated version along with other data analysis and plotting packages. Based on the analyses, the telemetry analysis tool has been changed to using Microsoft Visual Basic Enterprise Edition and PV-WAVE version 6.0.

The new implementation of TAT includes a summary database that allows fast access to common mnemonics for certain times during the recording of telemetry data during a pass. The summary data consists of the following for selected mnemonics for a given pass: a single value selected during a special point in the pass, the mnemonic's minimum value, the mnemonic's maximum value and their colors, as well as the mnemonic's average value. The reports and plots were also updated and expanded. The following section discusses the design of the new system.

3. Telemetry Analysis Current Implementation

Overview

The new telemetry analysis system was

designed using Microsoft Visual Basic and version 6.0 of PV-WAVE. Visual Basic communicates with PV-WAVE using dynamic link libraries (DLL) and gathers data from the SQL Server database using remote data objects (RDO). The telemetry analysis system consists of two Visual Basic processes: one to manage the user interface and provide both summary and detailed plots and reports, and another that gathers data from the SQL Server database and stores summary data in a local Access summary database.

Timing Results

The decision was made to use Visual Basic and RDO based on a set of timing tests that were conducted in order to determine the new architecture for the TAT. The testing consisted of gathering the data from a 12000 row table on the SQL Server, bringing it to a workstation, and storing the data locally in a file. The baseline test was done on the original Access implementation using attached tables. This time was compared with Visual Basic using recordsets, Visual Basic using the open database connectivity (ODBC) application programming interface (API), and Visual Basic using RDO. Table 1 summarizes the results of these tests.

along with the average value for selected mnemonics for each pass. For this satellite family, there are approximately 120 mnemonics that have data stored in the summary database. These mnemonics are those that have been determined to contain important indicators on the health of the satellite and are consistently used to assist in resolving anomalies. If there is an anomaly that requires data from a mnemonic that is not in the summary database, or more detail is needed than that in the summary database, the operator has the option to view detailed data from the SQL Server database, which contains all pass data for all mnemonics.

The data gathering process runs every hour and gathers data for all new passes in the SQL database. The process runs constantly in the background, and has no operator interface. It stores all its actions, including any problems encountered, in a table for later viewing by a system administrator. If the workstation where the summary database process resides goes down for any reason, the process will resume where it left off when the workstation is operational. This is accomplished by keeping information on the last pass stored for each satellite. When the data gathering process runs, it gathers all data from that last pass to the present time.

Table 1. Database Access Timing Results

	Access (baseline)	VB and ODBC API	VB and Recordsets	VB and RDO
Time (sec)	120	51	34	31
% Decrease		57	71	74

Summary Database and Process

The summary database is an Access database that stores a single value, the minimum value, and the maximum value and their colors,

The data gathering process has a user interface for administrative functions, such as deleting a pass from the summary database, inserting passes manually into the summary database, and viewing the table that shows the actions of the process, such as what passes were stored and any problem encountered in the storage process. The manual pass deletion or addition is used if there were any problems with storing the pass, or if a pass was recorded at another site and added to the SQL database at a later date. These capabilities were also used for development, and for bringing past passes into the summary database.

One of the more complex parts of the data gathering process is finding that point of time within the pass when the single value for the mnemonic is to be obtained. The algorithm for determining this point went through numerous iterations, because of the variations in conditions of different passes for different satellites. It is still being tested to determine if the algorithm will operate correctly under all circumstances. Any problems in determining the record point are documented with enough information to ascertain why the determination failed.

Summary Database Plots and Reports

The user interface process contains an option to view the summary data. Predefined plots and reports are available and generated weekly so the operators can look for trends and significant changes. The user can also generate custom reports and plots from the summary data by selecting mnemonics and a period of time. Figures 1, 2 and 3 are examples of the types of reports and plots provided.

Detailed Database and Process

The detailed database is an SQL Server database which stores all data for all satellite passes. This database is stored centrally on an NT machine and accessed by the TAT using RDO. As discussed earlier, the desire for faster data retrieval for commonly accessed mnemonics led to the creation of the separate summary database. This gives the operator the option of viewing either the full data from the SQL Server or the summary data from the summary database.

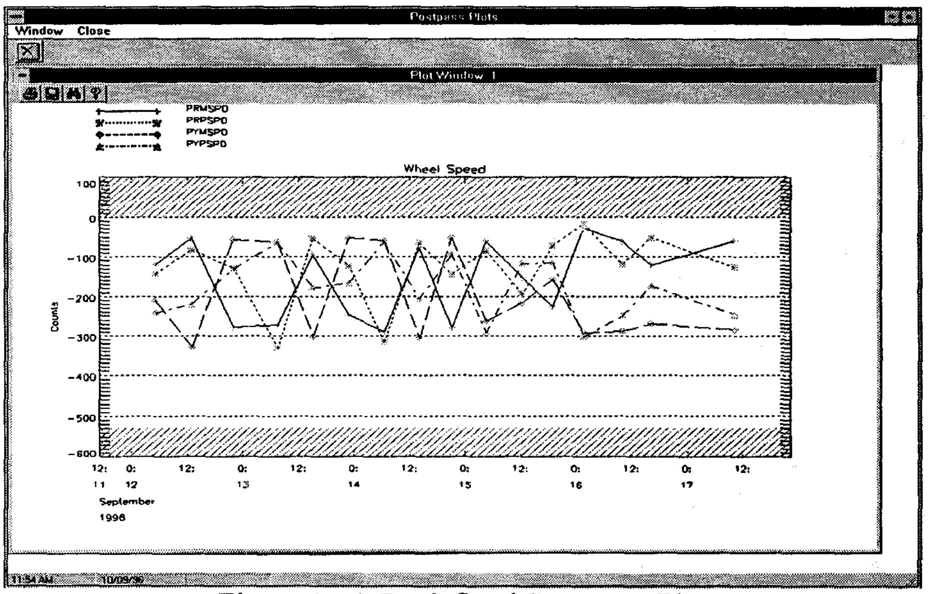

Figure 1. A Predefined Summary Plot

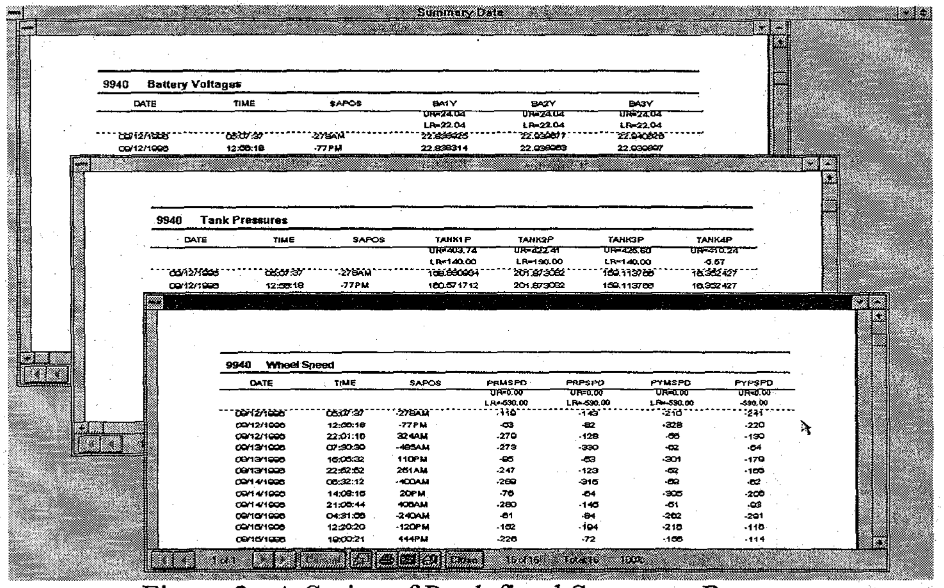

Figure 2. A Series of Predefined Summary Reports

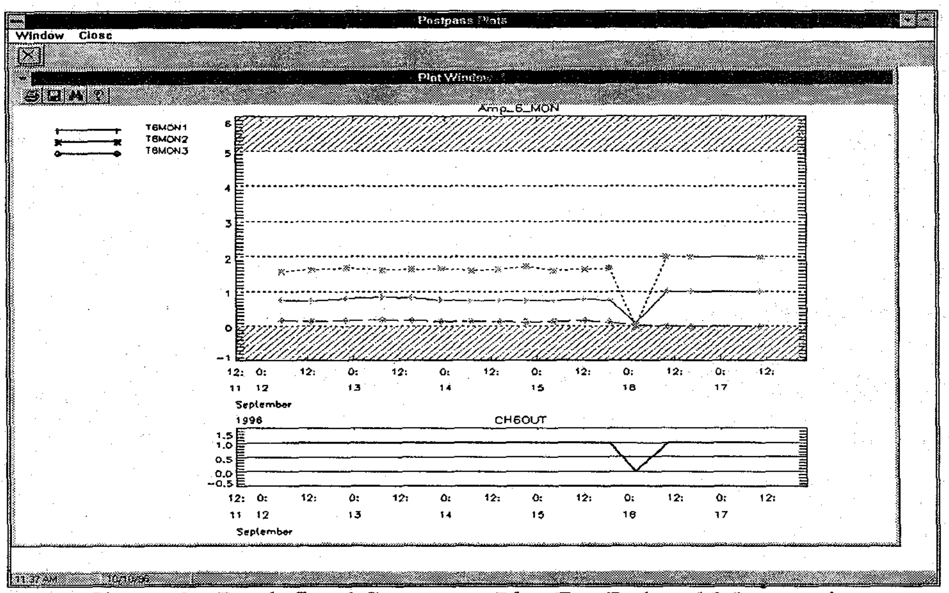

Figure 3. Predefined Summary Plot For Related Mnemonics

When using the full data from the SQL Server, all data from selected passes is retrieved from the central SQL database and stored temporarily in local tables. From this point forward in the detailed analysis session, any data examination carried out by the user uses this locally cached data, providing extremely fast response. The time consuming part of the process is therefore in the initial caching of the selected pass data in the local database.

The decision to cache all the pass data locally, instead of waiting for the user to select particular mnemonics for a pass and just bring those across for analysis, was made based on two factors. First, the amount of time to move an entire pass was not significantly slower than the amount of time to move only selected mnemonics across for analysis. Second, when there is an anomaly, the operator analyzes the passes involved in that anomaly extensively, looking at various mnemonics in those passes in different views. This approach provided the best overall performance for data analysis using the SQL server database and made data available in the manner best suited to the operator's use of TAT.

Among the numerous tables of the SQL Server database, the two accessed dynamically by TAT are the table that contains all satellite passes stored in the database ("Passes"), and the data tables where the pass data is stored for the satellites. The Passes table contains the satellite identification and time information, along with the name of the database table storing the data for the pass. Fields in the data tables contain the mnemonic name, mnemonic value, the start time for the value, the end time for the value, and the color of the value.

The other SQL Server tables used by TAT do not change very rapidly and are therefore stored locally on each workstation and updated when they change. For example, there is a table that contains information on all the mnemonics for all the satellites.

When TAT is started, it compares the last updated date for each of its locally stored tables with the last updated date on SQL Server for those tables. If TAT has an older version, it updates its local tables. This significantly decreases the SQL Server accesses and the time required to conduct analysis.

Detailed Database Plots and Reports

The Detailed Analysis portion of the program uses the data from the SQL Server database and provides numerous options to the operator for viewing, manipulating, and reporting on the data. The data from up to four satellite passes may be viewed at once and within those passes multiple mnemonics examined.

There are five types of plots that may be generated from the mnemonic data. The Actual Data plot is a straightforward graph of the actual data points and allows display of multiple mnemonics across multiple passes at once. The Extrapolated Data plot extrapolates data points in order to fill in gaps between passes. The third type of plot available is the Curve Fit graph which attempts to perform both a polynomial and a linear regression curve fit on the data set. A Fourier Analysis option calculates and plots a fast Fourier transform. Lastly, a Three-Dimensional plot allows one to compare two mnemonics by graphing them on a single plot. The time is plotted on the x-axis, one mnemonic plotted on the y-axis, and the other mnemonic displayed via the z-axis. The five graphing methods implemented provide the satellite analyst a diverse set of methods for inspecting and comparing data.

The process of creating a plot involves the retrieval of mnemonic data cached in local tables, formatting the data, storing it in files, and passing the file names and formatting information to graphics modules implemented using the PV-WAVE graphics language. All plots allow zooming, printing, and saving to file for later analysis. Multiple plots may be displayed, depending upon the number of passes and mnemonics selected. In those cases, all plots are displayed at once in a single window in order to allow the user to view all plots of interest at once.

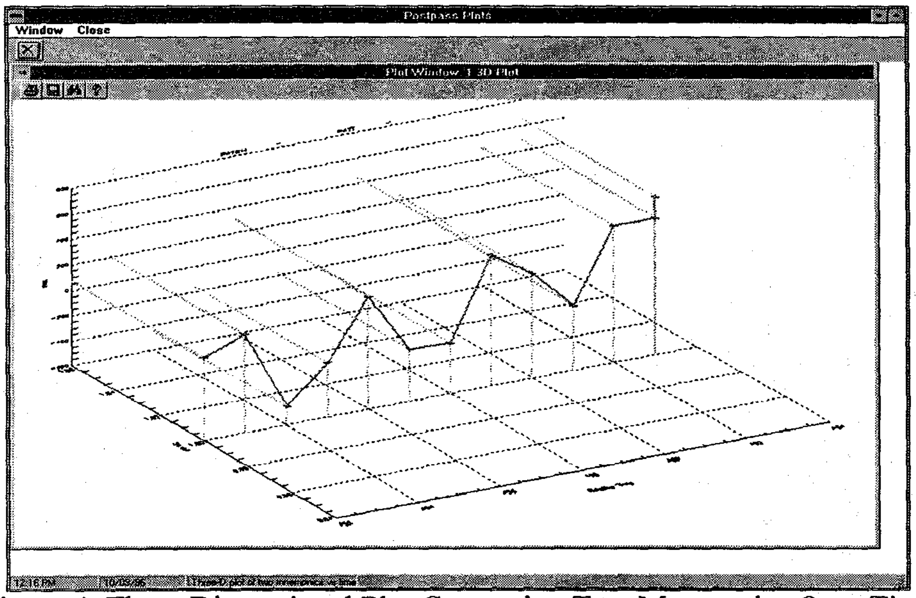

Figure 4. Three-Dimensional Plot Comparing Two Mnemonics Over Time

In addition to plots, data may be examined using reports, three types of which are made available. The Mnemonic Data report generates a report listing of all data points with their associated times and display colors. The Out of Bounds report will display a listing of any data values not having a color of green in order to quickly find possible anomalous points. Lastly, the Passes in Database report lists all passes stored in the database that occur between the earliest and latest passes currently under examination. This enables the user to quickly determine other passes that may exist in the current frame of interest. As with the plots, all reports may be zoomed, printed, or saved to file for later use.

Report generation is accomplished using Crystal Reports Professional, version 4.5. Crystal Reports functions simply by attaching a database table or tables to a report that displays selected database fields as determined during report design. When a particular report is selected by the user, the appropriate mnemonic data is retrieved from the local mnemonic database, other data as necessary gathered, any data manipulation conducted, and the report data is written to the designated table in the local database. The report itself is then instructed to display itself and the appropriate data, as stored in the database, is displayed.

As discussed previously, once pass selection is made, data for all mnemonics in that pass is retrieved and stored in a local database. Thus, the user may perform many analyses in a rapid and efficient manner. Various types of data examination may be promptly sampled between the plots and reports using different combinations of mnemonics, as all data is retrieved briskly from the local database.

4. Data Visualization Using PV-Wave

Graph and plot generation is accomplished using Visual Numerics Incorporated's PV-WAVE, version 6.0 command language. In addition to graphics routines, this software package provides data analysis routines used during plot production such as curve fit functions. The various plots of the satellite analysis tool are completed using subroutines written in the command language. The command language uses standard programming constructs such as procedures, functions, and loops. TAT data analysis and visualization subroutines make use of the standard, command language library of functions. Subroutines are read, compiled, and executed in a single step by the PV-WAVE interpreter.

For the generation of each plot described above, one or more subroutines were written rather than as subroutine parameters. The data files are read, and plots generated.

Dynamic data exchange (DDE), used previously for access to PV-WAVE, was discarded and replaced with the use of a dynamic link library (DLL). The PV-WAVE standard library includes the function, cwavec(), for use in dynamically linking its functionality to outside programs. The plotting subroutines written for TAT are invoked by way of the cwavec routine. The use of PV-WAVE via a DLL proved to be a more efficient and reliable method than the DDE interface used in the analysis tool previously.

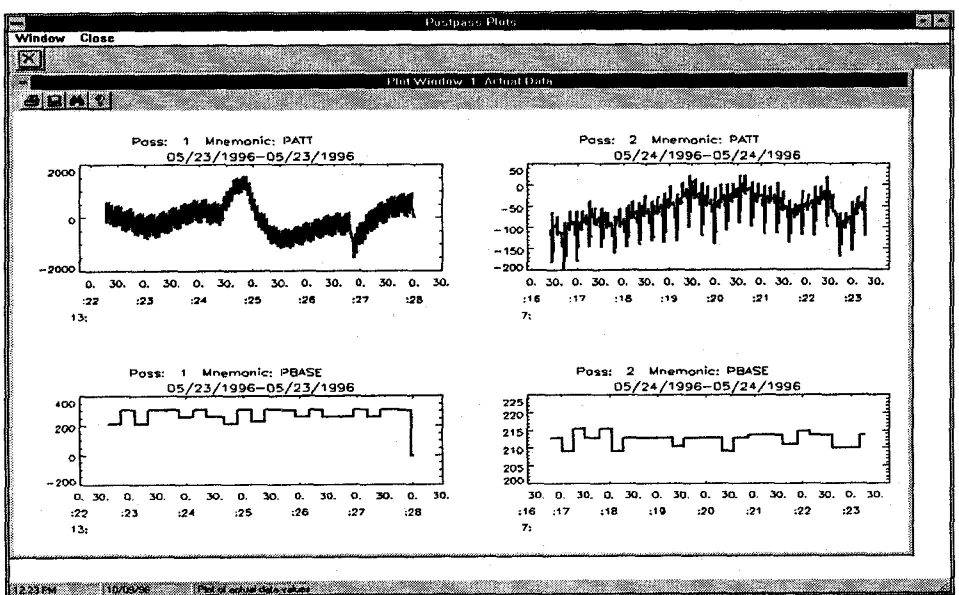

Figure 5. Plot Window Displaying Data for Multiple Mnemonics Over Multiple Passes

using the PV-WAVE command language. These subroutines are called by the main Visual Basic executable and are passed parameters indicating details such as what type of graphing to conduct and where graphing is to occur. Due to the large volume of data to be plotted, it is passed via files

Another important aspect of the use of PV-WAVE is the ability to direct where graphics are to be displayed. As mentioned previously, a problem with the earlier version of TAT was the inability of the graphics windows to behave as part of the main program. For any plot generated, PV-WAVE created its own window for display. This created problems when working in the original program since there was difficulty making the plot window a child of the main application. The plot window therefore did not behave as part of the main application, disappearing behind all other windows whenever other functions of the analysis application were used. This was fixed using the new version of PV-WAVE which allows for use of another application's windows. Thus, along with other parameters passed to each plot subroutine, is an argument indicating the graphics target window.

Version 6.0 of PV-WAVE has proven to be a great improvement over previous versions and curve-fitting have been modified extensively to make optimal use of PV-WAVE curve-fitting functions resulting in greater reliability than previously, but the routines are still not as accurate in producing a curve fit as desired. Difficulties in graphic and window re-sizing exist. These limitations are expected to be ironed out in future releases of the graphics command language.

5. Conclusions

The development process discussed here has resulted in a telemetry analysis tool that is reliable, efficient, and of value to the satellite engineer. The major revisions discussed have

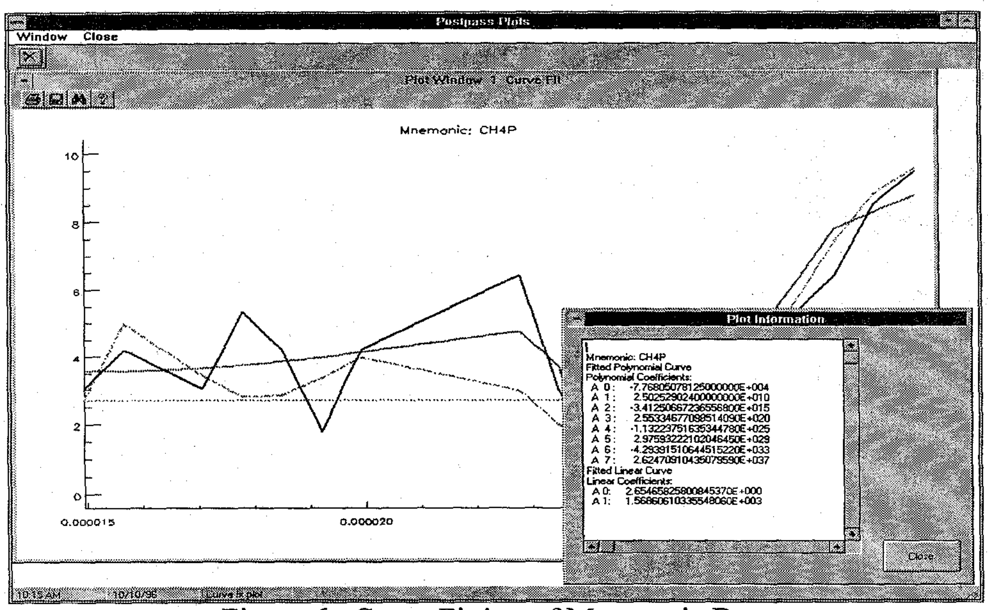

Figure 6. Curve Fitting of Mnemonic Data

provides good functionality for the telemetry analysis tool. However, some difficulties do persist. Problems, such as graphic placement in windows, require work arounds in order for the operator to view complete plot windows. PV-WAVE has a problem with cutting off the top of the upper plot when plotting multiple mnemonics in one window. Routines for resulted in a system that is much more robust, efficient, powerful, and accommodating to the user than its predecessor.

Data retrieval is faster than before and even automated in the case of summary data. Plots are stable, reliable, and fit seamlessly within the main application. Program design allows the use of commercial tools in a plug-and-play method via DLL's and standard paradigms such as ODBC. Thus, a data visualization tool found to be superior to PV-WAVE or Crystal Reports may easily be integrated into the system. TAT has proven to be a success from both the developer and maintenance points of view. Most importantly, it has been a success from the user's perspective as evidenced by its current use at Falcon Air Force Base.

Future work will continue on the telemetry analysis tool in order to enhance functionality for the user and optimize performance. New methods of data visualization, such as three dimensional graphics, are being investigated as possibilities for providing the user with additional useful methods of data examination. Performance enhancements may be possible by utilizing the next release of the PV-WAVE graphics package that is advertised as containing an open database connectivity (ODBC) interface. Using this new interface may increase efficiency by allowing plotting functions to directly access the databases and eliminate the need for data to pass through files. Future work will continue to build upon the improvements obtained from the development process presented here.

Dr. Nancy Crowley has been in the Air Force for over 18 years. Most of those years, she has worked in system and software development, software acquisition, and program management. She currently is the acting chief of the Space Operations and Simulation Division and develops systems and software for satellite operations. She holds a Ph.D. with a major in software engineering and a minor in artificial intelligence from the Air Force Institute of Technology. Her dissertation was in the area of object-oriented requirements analysis.

Vincent Apodaca is a computer scientist with a focus on software development and testing. He has developed software at Rockwell International and Nichols Research where his projects included expert systems, imaging, real-time hardware controls and data visualization. He has a M.S. in computer science from Lamar University.