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PROPOSAL FOR IMPLEMENTATION OF CCSDS STANDARDS FOR USE WITH SPACECRAFT ENGINEERING/HOUSEKEEPING DATA

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Abstract

Many of today's low earth orbiting spacecraft are using the Consultative Committee for Space Data Systems (CCSDS) protocol for better optimization of down link RF bandwidth and onboard storage space. However, most of the associated housekeeping data has continued to be generated and down linked in a synchronous, Time Division Multiplexed (TDM) fashion. There are many economies that the CCSDS protocol will allow to better utilize the available bandwidth and storage space in order to optimize the housekeeping data for use in operational trending and analysis work. By only outputting what is currently important or of interest, finer resolution of critical items can be obtained. This can be accomplished by better utilizing the normally allocated housekeeping data down link and storage areas rather than taking space reserved for science.

Background

This proposal began as a study to optimize the archival of spacecraft housekeeping data from the SAMPEX Small Explorer mission for use in long term data analysis and performance trending needs. As the study progressed, it became apparent that many of these optimization techniques could be put into the spacecraft itself by taking advantage of new advances in flight certified microprocessors and the options provided by the CCSDS protocol. Future missions could be programmed to detect most of the problems that the ground data systems currently look for and provide for higher resolution data to help in troubleshooting when a problem arises, filtering out unnecessary data when the spacecraft health is nominal.

When health and safety data is processed and analyzed, some data that is stored onboard in the recorder is filtered out on the ground and discarded. As long as parameters remain constant and configurations don't change, this information is redundant and unnecessary. Other data is output synchronously at to slow a rate to be of any use for anomaly analysis. This data may give indications of a problem, but not enough information to know exactly what is going on, or it may mask a problem for weeks or months, even years due too periodic sampling of the data that may be asynchronous to brief anomalous events.

It should be noted that attitude determination was not addressed in this study even though attitude data is usually considered a subset of the housekeeping data. Attitude data packetization algorithms should be specified so as to meet science data processing requirements rather than performance analysis requirements that are usually less stringent.

Types of housekeeping data

The housekeeping data for SAMPEX fell into one of six different general categories: discrete counters, digital status data, analog data, flight software memory dumps, flight software memory dwell data and science quicklook packets. Time was not included in this study as a separate category as it is a parameter in every CCSDS packet header and therefore usually is not a part of the application data field. Obviously, time must be transmitted in such a fashion as to know when each telemetered data value was sampled.

The first category, discrete counters, is the primary means to monitor and diagnose the performance of flight software and/or the command and data handling unit. This data falls into two general subcategories. These are counters that infrequently increment and those which constantly increment. The counters that infrequently increment include command execution counters, command execution error counters and miscellaneous error counters. These types of counters are of interest only when they change value. The counters that constantly increment include time, task execution counters, and data storage accounting statistics. Some of these counters are always of interest, some are only of interest during flight software diagnostic testing, and some are only of interest during real-time.

The second category, digital status data, consists of configuration data (items that can be modified by command), error flags, environmental flags (generally indicate some orbital characteristic such as day or night delimiters) and informational data. This data is generally supplementary data that helps to determine when something happened and, like the infrequently incrementing counters mentioned above, are of interest only when they change. Examples of this type of data include spacecraft event messages, calculated onboard table checksums, flight software load and dump information and error handler takeover reasons.

The third category, analog telemetry, is probably the most important data for monitoring the health and safety of the spacecraft. What is key here is getting the right amount of data to detect problems or degradation without monopolizing the onboard data storage space or the down link bandwidth.

The next two categories, flight software memory dumps and flight software memory dwell data, are generally used for flight software maintenance purposes and would probably only be output on receipt of a spacecraft command. Handling of this data is an entire subject in itself and is not specifically referenced in this paper.

The last category, quicklook data, is generally handled by onboard microcomputers and, for SAMPEX, is only output on receipt of a command. It was only included in the SAMPEX study since it is the only source of instrument housekeeping data available in the control center. These data packets consist of a one orbit sample of various instrument rate counters and housekeeping status.

Data Processing Functions for Data Analysis and Performance Trending

The data processing functions done for data analysis and performance trending are very similar to the data processing steps for science data analysis. The first step involves a quality and accounting assessment to ensure that an adequate amount of data is recovered for data analysis and performance trending. The raw data is generally archived to provide a backup in the event a data processing error is discovered in the future. Optional data merging may be done to combine real-time and playback data or to replace bad quality data with a better, retransmitted value. Finally, the data can be sorted by function or subsystem.

The next step generally involves ingesting the data values and affixed time-tags into a database for later access by analysis tools. This step includes processing the data and monitoring for high and low limit violations, verifying configuration and discrete state checks and optionally performing engineering unit conversions (if the storage database does not provide this function). At this point the data may also be processed to provide maximum/mean/minimum values of analog values for long term performance trending. This data may be processed for single orbits, daily or some other periodic unit of time.

After the data has been processed and stored in an on-line database, routine data analysis can be performed. This routine analysis function can generally be automated and may include creation of x/y plots for the thermal, communications or power subsystem as well as special processing for power budget monitoring and analysis or for attitude determination and control system verification.

Finally, some sort of orbit propagation may be done to provide a definitive history of actual spacecraft position over time. This data can be used both in subsequent anomaly investigation or for long term performance trending and is generally needed to isolate spacecraft problems that may be due to an environmental factor. In most circumstances, orbit accuracy requirements for science data processing are tighter than that required for performance analysis and therefore a commercial off the shelf orbit propagator, or ephemeri data provided for science data analysis, is sufficient. This data must be stored, or made available, to any plotting packages that would have access to the on-line spacecraft database and be used for analysis and trending.

Special data processing may then be required to further analyze any spacecraft anomalies. Also, short and long term trending may be done. Short term trending may involve comparing a sample orbit signature of a telemetry point with a comparable earlier orbit signature to monitor for degradation or orbit patterns. Long term trending may involve such things as plotting minimum, mean and maximum values of telemetry points (1 point per orbit or day, etc.) over a longer time span to monitor seasonal or longer term trends. Long term earth projection plots may be used to monitor single event upsets or other environmental effects on spacecraft performance.

Onboard packetization strategies

For the data that is only of interest when it changes, such as command execution counters, command execution error counters, other error counters and digital status data, onboard storage space could be saved if this data were stored only when something changes. Depending on how many telemetry points fall into this category, one or two packet formats (more if large amounts of these points exist or if separation by subsystem is desired) should be specified. To save storage space if there are more than a few of these points, two packets should be defined separating data that is expected to periodically change and data that should never, or very rarely, change.

This data could then be sampled synchronously onboard, formatted into a packet and compared to the previous sample. If the comparison showed a difference, the old and new (or just the new) packets could be stored. Else, the old packet could be discarded and the new packet saved for comparison with the next sample. The sampling rate should be frequent enough to provide the time of the change to within a few seconds and should also be frequent enough to catch every state transition. If a relay can be powered on and back off between samples, the ground operations team may never know that a transition occurred. If there is a concern of scheduling reads to quickly, the individual subsystem could maintain a history of the last few settings of the discrete and the associated times or just keep track of all transitions between readings and set a flag if more than one transition occurred since the last sampling.

Finally, this data could also always come down in real-time, if there is enough down link bandwidth, or could be stored or down linked on command. This would provide the ground operations team a sanity check on the data to ensure that a change does not go undetected due to a lost packet. Another possibility is to treat some or all of these items as spacecraft events and issue an event message containing the telemetry mnemonic, the previous and current values and the time of the transition rather than store the full data packet that contains a sampling of all of the discrete, infrequently changing values. The configuration and counter packet(s) could then be available for storage or real-time down link on command in order to provide sanity checks.

The next type of data is the frequently or constantly changing data. This category includes analog data, flight software task execution counters and data storage accounting statistics. Analog data, when synchronously stored, is generally compromised. By this, I mean that this data is usually stored at a rate that is to frequent when the spacecraft health is nominal and not frequent enough for analysis purposes when there is a spacecraft anomaly to investigate.

One way to improve upon this is to take advantage of current flight certified onboard computer capabilities (usually required to take full advantage of the CCSDS protocol anyway) to move analog and discrete monitoring functions (limit, state and configuration checking) from the ground data system to the spacecraft. This would give the spacecraft the ability to detect its own anomalies, take immediate command response to anticipated contingencies and provide higher resolution data for use in ground analysis when a discrepancy occurs. Analog data could be stored in a circular buffer onboard the spacecraft. This buffer would be sized to hold approximately one orbit, or other suitable time increment, of high resolution analog data. If a monitor violation is detected by the onboard computer, then the contents of the circular buffer, or an appropriate subset of that data, can be transferred to the data storage recorder for subsequent ground data analysis of the problem. During the rest of the time, this data could be filtered before being recorded such that enough data is always available to do performance trending, but higher resolution data is available for anomaly analysis. By allowing this circular buffer to be stored or down linked on command, daily high resolution or "typical orbit" plots could be maintained. Filtered data would then fill in the rest of the day.

With a more sophisticated onboard computer, the function of calculating and saving the maximum, minimum and mean values for a given telemetry point, on a per orbit or other incremental period, could also be migrated to the spacecraft. This could be particularly useful for power system analysis, where it is often desired to identify when a current or voltage spike may have occurred. Currently this is like looking for a needle in a haystack as the synchronous data sampling either results in the spike not being recorded or in the inability to determine exactly how long the event actually occurred. By combining min./mean/max. data with high resolution data output when a monitor is violated, work on detecting, monitoring and isolating power spikes could be greatly enhanced. Also, min./mean/max. data could give a good, quick view of the spacecraft thermal performance.

If the min./mean/max. data was sampled directly from the analog source, or the high resolution buffer, a better data set could be obtained onboard than could be calculated on the ground from the lower resolution, filtered data that would be stored onboard when spacecraft functions were nominal. This would result in better long term trending data.

Flight software task execution counters are primarily used for diagnostic purposes. Since these counters have a possibility of rolling over multiple times each second, this data needs to be output at a high rate to be of any use. An output of delta values or messages per second, vice absolute counts, could be more useful. Also, since this data is really a diagnostic tool, it should be filtered out and only stored or down linked on command, when necessary. It is also possible to provide flags to indicate that software tasks are running and execution counters are incrementing. Actual counts would only be needed if trying to study environmental effects on task loading or to diagnose a new flight software patch. For example, on SAMPEX we attempted to see if flight software tasks were running at a significantly different load during ground contacts or when over the poles when science data output increased due to increased particle events.

Data storage accounting statistics are generally only used during ground contacts to verify that the data stored onboard was completely captured on the ground during a recorder dump. Therefore, storage of this data is usually not necessary. However, it may be of interest to do a study of how often and when data is stored based on environmental factors. Therefore it may be desired to allow storage of this data in a fashion similar to the task execution counters mentioned above.

Another way to save onboard storage space for constantly changing telemetry points is to increase the efficiency of CCSDS packetization by increasing the packet size. Each packet header requires 112 bits. Packet size can be increased by supercomming the data (multiple samples assembled within the same packet), however this requires that the ground data system have the capability to split the packet apart and extrapolate the time code. Another way to increase packet size is to specify packet contents based on output frequency rather than by source. This allows fewer, larger packet types to be managed by the spacecraft, at a higher storage efficiency, but at the expense of being able to sort data by spacecraft telemetry source once on the ground.

The final types of data packets are those which are stored and/or down linked only on command. This already implies that this data would only be generated when needed and, other than combining data packets if possible, no other optimization techniques are necessary.

Implications to spacecraft data storage sizing

Since many of the proposals in this paper suggest event driven rather than synchronous data output, it is now more difficult to optimally size the amount of storage space needed for housekeeping data. Science data storage space is not optimized if housekeeping data storage space is sized for the worst case.

Therefore it is recommended that housekeeping storage space be sized to hold the expected amount of housekeeping data under nominal conditions, allowing for any additional storage space that may be desired to allow two or more down link opportunities for any particular data dump. Then some space could be reallocated from the science allotment, if needed, in order to store higher packet output rates generated when spacecraft algorithm's explained above increase the amount of housekeeping data saved. By sharing some science storage allocation, science data output can be maximized when spacecraft operation is nominal. This shared area could then be reallocated to housekeeping when spacecraft problems cause higher packet output rates to be needed. It may even be possible to set this up in a way that less valuable science data would be lost in the event of a problem. Even though this could result in periodic losses of some of the science data, it should allow more science to be recorded during nominal periods when the housekeeping data output is reduced to a minimum and could allow for more expedient detection and correction of small problems before they become big problems.

Summary

By taking advantage of the event driven nature of the CCSDS protocol and by migrating some of the basis data checks from the ground to the spacecraft, the output of spacecraft housekeeping data can be optimized to provide a more prudent balance with science data. By monitoring discrete telemetry, only information on state transitions or counter increments need be transmitted to the ground rather than synchronous output of redundant data. On command discrete telemetry packets can provide the ground with a sanity check. Also, by having the spacecraft monitor analog limits and subsystem configurations, analog data output can be throttled to provide increased data output rates when potential problems exist while filtering this output during nominal operations. By having the spacecraft calculate max./mean/min. data, long term trending of spacecraft performance can be greatly enhanced. Finally, by sharing recorder overflow space with science, optimum science output can be achieved when spacecraft performance is nominal and finer resolution housekeeping data can be output when there is an indication of a performance problem.

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