DATAware; A Graphical Approach for Decoding and Displaying Small Satellite Data and Telemetry

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Today's small satellites are capable of producing vast quantities of data from experiments and engineering telemetry. The requirements of the small satellite operator define how science and engineering data is treated. The small satellite operator typically does not have the financial resources for a worldwide network of downlink ground stations. These constraints require that the satellite's status must be ascertained within a relatively short window during a pass over a single or a few ground stations. Any anomalous operation needs to be quickly identified so that corrective action may be taken. In addition, the satellite operator is often the end user of the data gathered from the onboard experiments.

Currently, ground stations display data in a list format. The display requires decoding and analyzing the data, two distinctly different software algorithims. There is a need for a single software package to decode and display the experiment data and engineering telemetry in an easy to interpret format. A single software package will ease the burden of understanding satellite data decoding, calibration, and display. DATAware is being developed to fulfill this need.

Introduction

The function of Data and Telemetry Articulation software (DATAware) is to quickly display both experiment data and engineering telemetry in a graphical or tabular format. This will be done by treating each information source as the same type of information. The software will be able to process transmitted information from the satellite in quasi real time.

The processed data will be accessible via a system of pull down menus similar to today's advanced microcomputer applications. Selected information will be displayed in a graphical or tabluar form. This method of data display allows one software package to handle processing both types of information. DATAware is being designed for the ground station operator's convience. Graphical indicators and audible alarms will flag the satellite data outside preset parameters for operation of onboard systems. Diagnostic extensions of the basic software will allow quick troubleshooting of onboard problems and allow the operator to focus on returning the satellite to a fully operating condition. These features potentially will save the small satellite operator's their investment.

DATAware is being developed by the Students for the Exploration and Development of Space (SEDS) at the University of Alabama in Huntsville (UAH) for the SEDSAT-1 mission. SEDSAT-1 is a small satellite that is being prepared for as a secondary payload from a McDonnell Douglas Delta II second stage by NASA's Small Expendable-tether Deployer System via a 46 km tether. This satellite will provide information on the dynamics of propulsive tether deployment. SEDSAT-1 will be a technology demonstration platform for the new Boeing/Kopin AlGaAs/$CuInSe_2$ solar cells and the Ovonics nickel metal hydride NiMH batteries. These solar cells and batteries will require an augmented engineering telemetry capability to accurately characterize the operation of the onboard power system. After the tether deployment experiment is complete, the satellite will operate as an earth observation platform. SEDSAT-1 will carry two amateur radio transponders for the worldwide network of amateur radio satellite operators. The expected mission duration is three to five years.

Background

Existing Software for Satellite Telemetry Display

Today's satellite communication design normally uses a minimum of two channels for sending information. Experiment data and engineering telemetry are distributed among these channels. Even if only one downlink channel is used, engineering telemetry and experiment data are downlinked asynchronously. [1] Lack of synchronization makes it difficult for any given ground station to receive all of the information concerning the satellite during a specific time frame.

The telemetry data can be captured by software provided by the satellite producer or by the use of a standard communication format such as AX.25. An example of preprocessed telemetry is shown in Figure 1. The decoding of the telemetry requires the knowledge of the specific satellite's calibration equations. The calibration equations , in Figure 2, for the data shown in Figure 1. The final product is a converted list of information shown in Figure 3. The user may construct easily interpreted graphs and tables from the list of converted data , in Figure 2.

The whole process of downlink, calibration, and display is time consuming. An operator not familiar with the process would have difficulty in extracting useful information. When the use of a satellite is intended for a world wide audience, a direct method of data processing is needed for ease of understanding.

```
DOVE-1>TIME-1:PHT: uptime is 065/13:26:09. Time is Thu Feb 06 03:55:03 1990

DOVE-1>TLM:00:58 01:58 02:84 03:2E 04:58 05:58 06:6D 07:47 08:6A 09:6A 0A:A2
0B:D8 0C:E8 0D:D7 0E:00 0F:23 10:CC 11:AA 12:01 13:02 14:A2 15:90
16:8C 17:96 18:96 19:98 1A:94 1B:91 1C:9B 1D:99 1E:22 1F:5E 20:BC

DOVE-1>TLM:21:94 22:7A 23:28 24:24 25:30 26:00 27:00 28:01 29:00 2A:00 2B:00
2C:00 2D:2A 2E:00 2F:9A 30:C8 31:9B 32:12 33:EA 34:BC 35:92 36:A2
37:A1 38:AA 39:96 3A:00

DOVE-1>STATUS: 80 00 00 68 B0 18 EE 02 00 B0 00 00 B0 00 00 00 00 00 00 00
```

Figure 1 *Preprocessed Telemetry* [2]

Here are coefficients for decoding the TLM lines from the DOVE satellite. To get the RESULT ("human" value) of a telemetry number (N), solve this formula:

RESULT = A*N^2 + B*N + C.

In the following listing from the source code of the EZ DOVE program (written in BASIC), the first number (in quotes) is the item number, then item description, then C, then B, then A, then units.

```
DATA "00", Rx E/F Audio(W), 0, .0246, 0, V(p-p)
DATA "01", Rx E/F Audio(N), 0, .0246, 0, V(p-p)
DATA "02", Mixer Bias, 0, .0102, 0, Volts
DATA "03", Oscillator Bias, 0, .0102, 0, Volts
DATA "04", Rx A Audio(W), 0, .0246, 0, V(p-p)
DATA "05", Rx A Audio(N), 0, .0246, 0, V(p-p)
DATA "06", "Rx A Discrim ", 10.427, -.09274, 0, kHz
DATA "07", Rx A S Meter, 0, 1, 0, Counts
DATA "08", Rx E/F DISC, 9.6234, -.09911, 0, kHz
DATA "09", Rx E/F S Meter, 0, 1, 0, Counts
DATA "0A", +5 volt bus, 0, .0305, 0, Volts
DATA "0B", +5V Rx Current, 0, .1, 0, mA
DATA "0C", +2.5 volt VREF, 0, .0108, 0, Volts
DATA "0D", "8.5 volt bus  ", 0, .0391, 0, Volts
DATA "0E", IR Detector, 0, 1, 0, Counts
DATA "0F", LO Monitor I, 0, .037, 0, mA
DATA "10", +10 volt bus, 0, .05075, 0, Volts
DATA "11", GASFET Bias I, 0, .026, 0, mA
DATA "12", Ground REF, 0, .01, 0, Volts
DATA "13", +Z Array voltage, 0, .1023, 0, Volts
DATA "14", "Rx Temp    ", 101.05, -.6051, 0, °C
DATA "15", +X (RX) Temp, 101.05, -.6051, 0, °C
DATA "16", Bat. 1 volts, 1.7832, -.0034084, 0, Volts
DATA "17", Bat. 2 volts, 1.7978, -.0035316, 0, Volts
DATA "18", Bat. 3 volts, 1.8046, -.0035723, 0, Volts
DATA "19", Bat. 4 volts, 1.7782, -.0034590, 0, Volts
DATA "1A", Bat. 5 volts, 1.8410, -.0038355, 0, Volts
DATA "1B", Bat. 6 volts, 1.8381, -.0038450, 0, Volts
DATA "1C", Bat. 7 volts, 1.8568, -.0037767, 0, Volts
DATA "1D", Bat. 8 volts, 1.7868, -.0034068, 0, Volts
DATA "1E", Array voltage, 7.205, .072, 0, Volts
DATA "1F", +5  volt bus, 1.832, .0312, 0, Volts
DATA "20", +8.5 volt bus, 5.265, .0173, 0, Volts
DATA "21", +10 volt bus, 7.469, .021765, 0, Volts
DATA "22", BCR set point, -8.762, 1.159, 0, Counts
DATA "23", BCR load I, -.0871, .00696, 0, Amps
DATA "24", +8.5V bus I, -.0092, .001699, 0, Amps
DATA "25", +5  V bus cur., .00502, .00431, 0, Amps
DATA "26", -X array cur., -.01075, .00215, 0, Amps
DATA "27", +X array cur., -.01349, .00270, 0, Amps
DATA "28", -Y array cur., -.01196, .00238, 0, Amps
DATA "29", +Y array cur., -.01141, .00228, 0, Amps
DATA "2A", -Z array cur., -.01853, .00245, 0, Amps
DATA "2B", +Z array cur., -.01137, .00228, 0, Amps
DATA "2C", Ext. Power cur., -.02, .00250, 0, Amps
DATA "2D", BCR Input cur., .08122, .00317, 0, Amps
DATA "2E", BCR Output cur., -.01724, .00346, 0, Amps
DATA "2F", Battery 1 temp, 101.05, -.6051, 0, °C
DATA "30", Battery 2 temp, 101.05, -.6051, 0, °C
DATA "31", Baseplate temp, 101.05, -.6061, 0, °C
DATA "32", FM TX#1 RF out, .0256, -.000884, .0000836, Watt
DATA "33", FM TX#2 RF out, -.0027, .001257, .0000730, Watt
DATA "34", PSK TX HPA temp, 101.05, -.6051, 0, °C
DATA "35", +Y array temp, 101.05, -.6051, 0, °C
DATA "36", RC PSK HPA temp, 101.05, -.6051, 0, °C
DATA "37", RC PSK BP temp, 101.05, -.6051, 0, °C
DATA "38", +Z array temp, 101.05, -.6051, 0, °C
DATA "39", S band TX out, -.0451, .00403, 0, Watts
DATA "3A", S band HPA temp, 101.05, -.6051, 0, °C
```

Figure 2 *Calibration Equations* [2]

DATAware Concepts

Data and telemetry articulation software, (DATAware) starts with the concept of treating experiment data and engineering telemetry as the same type of information. By combining the information digitally and sending it down on one channel DATAware allows the operator to produce a complete system of graphical or tabular views of the satellite[3] If experimental data reveals something unexpected, telemetry will add to the experimenter's view of status of the satellite. This will help the experimenter understand the experiment's results.

DATAware is "smart software." Being "smart" means that the software knows how to separate and interpret experiment data and engineering telemetry. The data and telemetry may be stored in separate files for future processing. Simultaneously, the information may be displayed on the computer screen in the form of graphs or concise tables. By adding automatic processing, the operator is able to discern a system view of the experiments and the satellite in "real-time." DATAware adds to the productivity of the operator by performing the tedious decoding, calibration, and graphing of the satellite data.[4] In post down-link processing, the user may save the displayed information in either the Graphics Interchange Format (.GIF) or the Tagged Image File Format (.TIFF).

```
Time is Thu Feb 08 03:55:03 1990
Rx E/F Audio(W) 2.1848 V(p-p)
Rx E/F Audio(N) 2.1648 V(p-p)
Mixer Bias 1.3484 Volts
Oscillator Bias .4692 Volts
Rx A Audio(W) 2.1848 V(p-p)
Rx A Audio(N) 2.1848 V(p-p)
Rx A DISC    .31834 kHz
Rx A S Meter 71 Counts
Rx E/F DISC -.88226 kHz
Rx E/F S Meter 106 Counts
+5 volt bus 4.941 Volts
+5V Rx Current 21.6 mA
+2.5 volt VREF 2.5056 Volts
8.5 volt bus    8.4065 Volts
IR Detector 0 Counts
LO Monitor I 1.285 mA
+10 volt bus 10.353 Volts
GASFET Bias I 4.42 mA
Ground REF .01 Volts
+Z Array voltage .2046 Volts
Rx Temp      3.0238 °C
+X (RX) Temp 13.9156 °C
Bat. 1 volts 1.26149 Volts
Bat. 2 volts 1.26806 Volts
Bat. 3 volts 1.26876 Volts
Bat. 4 volts 1.25243 Volts
Bat. 5 volts 1.27335 Volts
Bat. 6 volts 1.28068 Volts
Bat. 7 volts 1.27157 Volts
Bat. 8 volts 1.26556 Volts
Array voltage 9.653 Volts
+5  volt bus 4.8648 Volts
+8.5 volt bus 8.5174 Volts
+10 volt bus 10.6902 Volts
BCR set point 132.636 Counts
BCR load I .1921 Amps
+8.5V bus I .059184 Amps
+5  V bus cur. .2119 Amps
-X array cur. -.01075 Amps
+X array cur. -.01349 Amps
-Y array cur. -.00957 Amps
+Y array cur. -.01141 Amps
-Z array cur. -.01853 Amps
+Z array cur. -.01137 Amps
Ext. Power cur. -.02 Amps
BCR Input cur. .19436 Amps
BCR Output cur. -.01724 Amps
Battery 1 temp 7.8646 °C
Battery 2 temp -19.97 °C
Baseplate temp 7.2595 °C
FM TX#1 RF out .0367744 Watt
FM TX#2 RF out 4.28863 Watt
PSK TX HPA temp -12.7088 °C
+Y array temp 12.7054 °C
RC PSK HPA temp 3.0238 °C
RC PSK BP temp 3.6289 °C
+Z array temp -1.817 °C
S band TX out .5594 Watts
S band HPA temp 101.05 °C
```

Figure 3 *Decoded Telemetry* [2]

The .GIF format will allow the user to import displayed data into other graphics enhancement software packages for additional processing. The .TIFF format will allow the information to be included in a written document. Use of DATAware results in a very fast turn around time, from receiving the information to final presentation. The operator may also save the data in a tabular format for use in spreadsheet software packages.

DATAware and SEDSAT-1

The University of Alabama in Huntsville chapter of The Students for the Exploration and Development of Space is currently involved in producing the tethered satellite, SEDSAT-1. A tether is a cord connecting the satellite to the rocket from which it was deployed.[5] The satellite is planned for a launch on the third flight of NASA's small expendable deployer system for tethered satellites in 1993.[6] SEDSAT-1 will house the following student experiments:

1. SEDS Earth Atmospheric and Space Imaging System (SEASIS): SEASIS will utilize two cameras, one for space and earth pictures and the other for spectrography of earth's atmosphere. The camera used for capturing space and earth images will use a panoramic annular lens (PAL). This lens produces a circular image requiring software to convert the image to a rectangular form.[7]

2. Three-Axis Accelerometer System (TAS): this system measures and reports the changes of velocity of the satellite . TAS will also serve to detect micrometeorite impacts upon the satellite. [7]

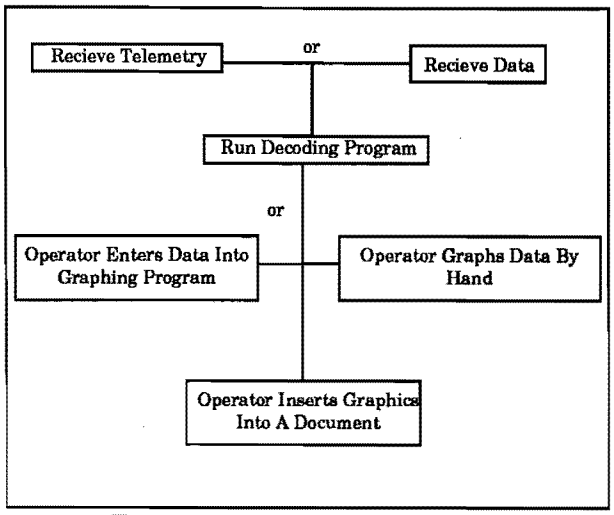

Figure 4 *Traditional Processing*

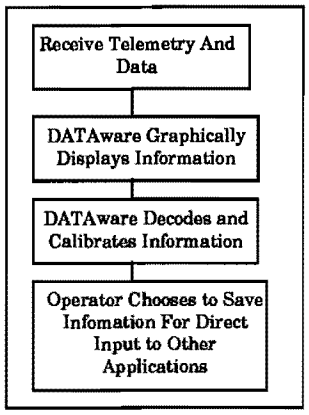

Figure 5 *DATAware Processing*

The information produced by SEDSAT-1 will be images from SEASIS, numerical data from TAS, and all of the telemetry reflecting the status of the satellite's systems. The satellite will be transmitting the data over the worldwide amateur radio network. The majority who examine information from SEDSAT-1 will need DATAware. DATAware will display the information from the satellite in a graphical and tabular format in a user friendly fashion. The data produced by SEDSAT-1 is ideally suited for this method of presentation. Figure 4 and 5 illustrate the advantage of DATAware processing over traditional methods.

Engineering Telemetry Display from SEDSAT

SEDSAT-1 will produce a large quantity of engineering telemetry to support the characterization of the solar arrays and batteries, as well as the satellite's other systems. The quantity of information generated will be greater than computer's ability to display at any one time. For this reason, the user must decide what data is most important to focus on during data reception. The rest of the information will have to be examined in post reception time.

The form of graphical or tabular presentation will depend on the system being examined and the operator's choice. Typical graphical examples include voltage versus time curves for battery status, current versus voltage curves for the solar arrays, and transponder input power versus time.

Experiment Data Display from TAS

The Three-Axis Accelerometer System aboard SEDSAT-1 will produce data on the X, Y, and Z accelerations of the satellite and data on the temperature of each of the three accelerometers. DATAware will graph the TAS data versus time on the display monitor as the information is decoded. DATAware will also integrate the TAS X, Y, and Z temperature information to give the bias offset error correction in acceleration due to temperature. The TAS data may also be presented in the form of tables.

Experiment Data Display from SEASIS

The SEDS Earth Atmospheric and Space Imaging System will produce data in the form of images. SEASIS will produce these images in a variety of forms. DATAware will be able to display the components of a RGB signal, from individual CCD arrays. DATAware will also be capable of displaying the NTSC or composite RGB format of SEASIS's images. By producing data in these formats, DATAware will be able to perform multi-spectral image processing after data reception.

Post Reception Processing

Engineering Telemetry

The operator will be able to examine all engineering telemetry downlinked from the satellite. This information will be displayed as graphs or tables with a operator selectable scale. Whole orbit engineering telemetry will also be displayed. If any of the engineering telemetry exceedes operator pre-set limits, an audible alarm with a displayed message will be provided. The displayed information may be saved as it appears on the screen in either a .GIF or .TIFF format.

Experiment Data from TAS

The TAS data will be displayed in the same manner as engineering telemetry. In addition, DATAware will process the TAS data to produce graphical representations of the velocity vectors in the X, Y, and Z. These vectors will indicate the accelerations that the satellite is going under at a specific time. DATAware will analyze the TAS data for sudden velocity changes and indicate these events to the operator as possible debris impacts on the satellite. As with engineering telemetry, the operator may save the displayed information.

Experiment Data from SEASIS

SEASIS images require a variety of image processing capabilities. The PAL system requires a software capability to transform a portion of the circular image to a standard rectangular image. A rectangular image is required for normal viewing.

A large percentage of the received images will require image processing. The capability to adjust the color palettes of the images to brighten and darken the images is required. DATAware features also invert the color palette of any image to produce a negative.

SEDSAT-1 will be constantly rotating. This rotation will cause the SEASIS images to be captured at random orientations. DATAware will electronically rotate any image by 90 degrees to aid the operator. DATAware will also compensate for the high altitude of SEDSAT-1 by digitally magnifying images by factors of two. These image processing capabilities ensure that the operator will have access to all the information in the image.

Conclusions and Recommendations

DATAware methodology in data processing provides:

1) reduction of overall complexity from the operator's point of view will be seen when the traditional method Figure 4 and the DATAware method Figure 5 are compared,

2) the satellite data with greater speed and efficiency then traditional methods. DATAware derives its speed by handling engineering telemetry in the same manner as experiment data. This allows the same processing routines to be used for both types of information,

3) the benefit of removing the burden of tedious processing off the operator. DATAware accomplishes this by decoding and displaying the satellite's downlinked information. In addition, DATAware will display a message and sound an alarm when any of the satellite's data exceeds pre-set conditions set by the operator,

4) output of DATAware in a simplistic graphical or tabular format.

This data and telemetry articulation method of information presentation, DATAware, is ideal for the requirements of most small satellites.

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