VISTA–Computed motion pictures for space research

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INTRODUCTION

The application of digital computers to reduction of telemetry data assumes an increasingly important role in the analysis of physical problems.[1] Even after reduction of the raw sensor data, an immense volume of resultant data remains. Thus there is a constant need of new tools for computer-aided analysis, synthesis and display of scientific results.

Graphic aids have evolved from printer-listings, through lineprinter plots to a wide range of x-y plotter techniques. Cathode Ray Tube devices (hard copy and one-line console) have introduced the latest generation of display capability. The trend, with this latest capability, is from static x-y plots to dynamic time-sequence displays.

This paper presents a generalized technique for generation of off-line CRT motion-picture displays of objects in three-dimensional space. Initial implementation of the system, called VISTA* (Visual Information for Satellite Telemetry Analysis), uses the Univac 1108 computer to generate time-sequence displays for output on the Stromberg Carlson 4020 microfilm plotter. The system accepts satellite orbit and attitude data and produces motion pictures illustrating the three dimensional position and orientation of the spacecraft in orbit, relative to one or more celestial bodies.

VISTA—General description

VISTA is a generalized system which accepts spacecraft orbit and attitude information and creates a physical picture of that data. The picture is not what is normally referred to as a data plot but rather a true representation of the spacecraft in orbit about a central body. The program output is synchronized with orbit time and is used to prepare multiple frames of 16 mm or 35 mm film on the SC-4020.

Current statistics indicate that one to two 1108 computer seconds is required to produce each individual frame (as illustrated in Figure 2). This variation in computer time is due to change occultation requirements. Computing time approaches a maximum when one body occults a dense portion of the earth's shoreline. At a camera rate of 16 frames per second, one minute of viewing time requires 24 minutes of 1108 computer time.

When the film is viewed through a projector as a motion picture, a continuous time history of the motion and orientation of the spacecraft is observed thus enabling a viewer to assimilate in a few seconds a large volume of data while subjecting the data to a rapid and comprehensive analysis.

There exist two major subsystems in VISTA over which the user has complete control and the potential for dynamic alteration:

1. Presentation of a mapped earth system and a spacecraft body system, ranging from a simple point-mass display to an orthographic projection of a solid spacecraft, which can be viewed from any arbitrarily chosen vantage point.
2. Presentation of data from an experiment aboard the spacecraft in one or more of several forms designed to aid the viewer in his analysis of the data.

*VISTA was developed by Computer Sciences Corporation for NASA-GSFC.

The first subsystem is concerned with the dynamics and the orthographic projection of bodies in motion in some arbitrarity specified coordinate system. In the case of three-dimensional objects, construction lines, object lines and detailed markings not visible to the viewer are automatically deleted from projection. This "hidden line" capability is used when occultation occurs between one or more of the included bodies. The user of the VISTA system has complete control over the desired view angle or vantage point. The viewers location and view vector may be either static or dynamic.

The second subsystem is primarily concerned with presenting and formatting data, title frames and selected overlay information. In this area, the prime objective was to overcome the inherent jitter associated with data plotting in a motion picture atmosphere and at the same time include complete data presentation capabilities. Both objectives have been successfully achieved and a wide variety of options and presentation formats are included to aid the viewer in his analysis of the data. These capabilities include presentation of data in the form of a "clock" with the hands indicating orbit sensor measurements. The speed at which the different hands move reflects relative speed and acceleration of the data variables. Two and three dimensional grids are also available where the latter may be rotated to a "best" view. Either the data or the grid can be oriented for rapid recognition as the frames are repeatedly updated and projected. A "marker" is also available, which points to the specific data point associated with the given display.

Although both of these subsystems are of equal importance, this report is addressed to the capabilities and techniques concerned with the dynamics and the orthographic projection of bodies in motion.

Spacecraft

VISTA was originally developed as an aid in the checkout of an attitude computation program for the Orbiting Geophysical Observatory (OGO). The OGO spacecraft, depicted in Figure 1, carries into orbit about the earth, a large number of varied geophysical experiments. A greater understanding of the earth, and of earth-sun relationships will be obtained from them. The experiments will supply data on such phenomena as auroras and low energy solar particles.[3]

OGO has three main physical components: A Main Body, a Solar Oriented Experiment Package (SOEP), and an Orbital Plane Experiment Package (OPEP). In orbit the Observatory has five degrees of freedom: rotation of the Main Body about each of its principal axes, rotation of the SOEPs with respect to the Main Body, and rotation of the OPEPs with respect to the Main Body. The rotations of the Main Body about the

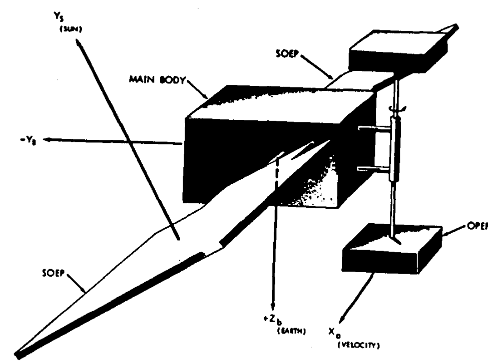

Figure 1—OGO spacecraft

longitudinal (Y) axis and about the solar array (X) axis are controlled so that the Body (Z) axis is directed toward the center of the earth. The rotation of the Main Body about the Z axis and the rotation of the solar array about its shaft axis are controlled so that the array face is aligned perpendicular to the sun line. The rotation of the OPEP with respect to its shaft is designed so that it tracks the component of the velocity in the orbital plane. Therefore, in order to define the orientation of the spacecraft there exist nine vectors, each with three components in inertial coordinates. Add to these 27 numbers other quantities of position, velocity, latitude, longitude, height, etc., and it can readily be seen that for any instant in time there is a large amount of interrelated data which is difficult, at best, to simultaneously correlate for analysis while at the same time verifying the overall spacecraft system response.

Coordinate systems

Within VISTA three coordinates systems, central or reference, body, and image, are used to describe the rotation and translation of the various bodies introduced into the viewing system and orient them in a proper viewing perspective.

Position and orientation information relating the body to the central coordinate system and similar criteria relating the image coordinate system to the reference system are sufficient to prepare the frames as shown in Figure 2. In the development of these frames (and the resulting motion picture) the central coordinate system was defined by information supplied from time sequenced orbit and attitude data on magnetic tape.

Such data as vehicle position, velocity and sun position are expressed as vectors in the geocentric equatorial inertial system. Spacecraft axes orientations, also expressed in this system, are given as unit vectors and

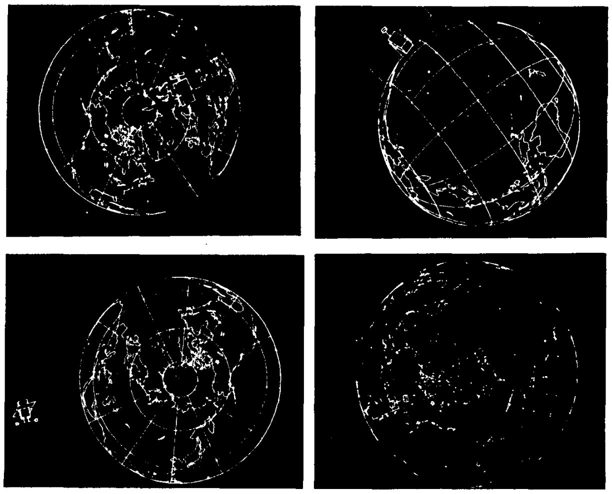

Figure 2—Projected frames

as such are directly applicable for use in the VISTA rotational matrices. Other information relating to the earth such as latitude and longitude of the subsatellite point are given in geodetic coordinates.

In VISTA, the image system is formed with the earth at the center and the viewer located on the + Z axis. The X, Y plane thus becomes the image raster "screen" to which all orthogonal projections are made. This image system may be rotated from the central inertial system by ordered angular rotations about one or more specified axes. Any inertial vector available in the data may be selected as the base view vector, i.e., vector along the line of sight of the VISTA "camera" taking the motion picture, and the appropriate angular rotations will be automatically generated. Additional rotations from the selected vector may be applied providing the capability of viewing the central system from any desired vantage point. In Figure 2 four views of the earth and the OGO spacecraft are shown for the same portion of the orbit.

Models

The geometry or shape of a non-spherical body is entered as a set of X, Y, Z points where each point describes the intersection of two or more lines or the intersection of a line and a surface. In order to reduce the complexity for intricate bodies, these points are numbered and plottable lines and body surfaces (polygon loops) are specified in terms of these numbers. When a body composed of hinged parts (e.g., the solar arrays on the OGO), requires that these parts vary with respect to each other then the points representing the "components" are grouped together. Several bodies may be introduced to the system in terms of points, lines, loops and components and projected simultaneously. Points grouped as components are rotated and translated to the image coordinate system where the line descriptors define plottable line segments and the loop descriptors are used in the final occultation testing.

The body represented in Figure 3 is a partial representation of the OGO spacecraft consisting of the main body and one solar array. The figure as shown is described with 14 points. Since the solar array rotates about the main body axis as it maintains alignment with the sun, points 1 through 8 are grouped as one component (the main body) and points 9 through 14 as another (the solar array). Seventeen lines and seven loops complete the description. As an example, the Y face of the main body is composed of lines (1,2), (2,3), (3,4), (4,1) and forms one loop.

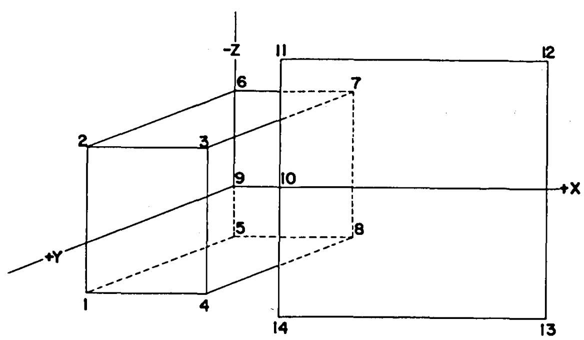

Figure 3—Partial OGO

This type of body description was a good balance between the ease of introduction of bodies into the computer (e.g., from scaled engineering drawings) and the ease of operation and projection in an internal computing sense. An interesting feature of this method is the ability to pass vectors (arrows) through the vehicle representative of such quantities as the magnetic field through which the vehicle is passing. Further, since the spacecraft is originally in alignment with the inertial axes, the rotation matrices to orient the spacecraft properly can be directly applied.

The earth as a spherical body is located at the center of the inertial coordinate system. A mapping of the shoreline features of the earth's surface is an additional input to the system consisting of approximately 8000 vectors. Optionally calculated and added to this mapping set are approximately 2500 vectors defining lines of longitude and latitude. (Samples of this representation of the earth are shown in Figure 2). The rotation of the earth in the VISTA model is driven by time as taken from the orbit data. The relative size and shape of the earth-spacecraft system is in part determined by the spacecraft position vector (magnitude) and in part by the location of view of the entire system.

In cases where it is desirable to include the moon or other major planets in the view, as with lunar orbits or approaches, these bodies are introduced into the system as spheres with appropriate surface mapping features. Proper position and orientation for these "special" bodies is achieved by utilizing ephemeris information and interpolating with the spacecraft time.

Hidden lines

As previously mentioned, one problem which had to be solved for the general case in order to achieve the desired effect was that of the hidden lines or occultation. This is a visibility determination; therefore, the selection of valid plottable line segments in the image coordinate system is performed last. All shoreline data as well as meridians, etc., are tested and those with negative Z values relative to the sphere center are immediately rejected. In this sense, spheres on which large amounts of data lie are handled in a somewhat different manner than the general manner applied to rectilinear figures. In the latter case, all lines associated with these figures that intersect others are broken into separate segments such that no two line segments intersect on the image plane. Examining the relationships of this new set of line segments and the body surface loops is sufficient for determining valid lines. A line segment is invalid if its midpoint falls behind and inside some loop; otherwise, it will be plotted.

This test for line validity is accomplished in two separate steps. The first is the "inside," "outside" determination; the second, the "front" or "back." Two different algorithms have been used for the first test—both successfully. Both solutions rely on lines being constructed on the image plane from the point to be tested (line midpoint) to each vertex of the particular polygon loop forming a set of triangles. One method computes and sums the interior angles about the test point. If the sum is equal to 360°, the point lies inside the polygon and may not be plotted. The other method computes in order the triangular areas. A change in sign in the area of any triangle determines that the point lies outside the polygon and will be plotted.

The second and final test for line validity is accomplished by constructing a line parallel to the view vector from the test point to the loop plane. If the point of intersection has a larger Z value than the test point itself, the point lies behind the plane and will not be plotted. Several optimization techniques are employed which effectively reduce needless validity testing. One such technique first examines minimum and maximum component or body values projected on the image plane and avoids body to body occultation testing when appropriate.

Dynamic control

All system parameters can be modified from the computer operator console as the system is running. In addition, selected parameters (view, zoom) may be assigned to continuous alteration on a frame by frame basis and controlled by the computer sense switches. Thus additional bodies may be introduced to the system and current ones modified. In this dynamic fashion, spacecraft and booster separation may be performed with relative ease. All transitions between views are made smoothly so that no discontinuity is noticed when the film is being projected.

Future applications

VISTA or VISTA-like computer techniques have several obvious applications, and, with some imagination, several not so obvious extensions. Two notable applications in space research are for manned spaceflights and for a galactic probe.

For manned spaceflight, VISTA, modified for realtime processing, would allow ground based observers to "see" docking maneuvers, rendezvous, or even a lunar touchdown. For these applications the user's facility for controlling the field of view would enable the viewer to observe the surrounding environment from any desired vantage point. The value of a viewing capability in rapid detection and analysis of anomalies in spacecraft motion in immeasurable.

Another application of VISTA would be the display of the orbit of a galactic probe. To show such an orbit the coordinate system used could be heliocentric (sun centered) rather than geocentric (earth centered). The system view chosen could be approximately normal to the planetary orbital planes. In viewing a motion picture of such an orbit not only would a time compression occur (orbital period measured in years, viewing time in minutes) but the relative locations of planets to the spacecraft and their influence could readily be seen and appreciated.

A more down to earth application of an extended VISTA is in air traffic control. The motion depicted on a CRT and the change of reference capabilities could significantly augment the controller-radar system. As an example the center of the coordinate system (radar) for a controller would normally be the tower. However, if any doubt arose concerning the vectoring of two aircraft the view of the controller could immediately be changed for better definition of the situation. If the same radar information could be fed to hybrid computers aboard each aircraft and viewed there, the center of the coordinate system could be the individual aircraft and the pilot could "see" what was in his vicinity as well as the directions of travel. Possible, yes—practical is another question.

SUMMARY

The VISTA system is designed to aid the space science analysis effort by preparing motion pictures which are realistic representations of the desired situation. This type of visual presentation permits a rapid correlation and intuitive understanding of the relationships of dynamic bodies and subjects all data to a more rapid and comprehensive analysis in a manner not available through reading lists of numbers or even plots of some particular parameter.

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