Visualization Experiences and Issues in Deep Space Exploration

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Abstract

Visualization tools play a key role in the exploration of outer space. Since it is difficult and expensive to send humans to other planets, immersive visualization of such hostile environments is as close as we will get for some time. Visualization is also used in a variety of supporting roles for deep space missions, from simulation and rehearsal of planned operations to analysis of spacecraft state to analysis of science data returned from a variety of instruments. The panelists will discuss their experiences in collecting data in deep space, transmitting it to Earth, processing and visualizing it here, and using the visualization to drive the continued mission. This closes the loop, making missions more responsive to their environment, particularly in-situ operations on planetary surfaces and within planetary atmospheres.

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Introduction

Visualization tools play a key role in the exploration of outer space. Since it is difficult and expensive to send humans to other planets, immersive visualization of such hostile environments is as close as we will get for some time. Visualization is also used in a variety of supporting roles for deep space missions from simulation and rehearsal of planned operations to analysis of spacecraft state to analysis of science data returned from a variety of instruments. But deep space throws up many roadblocks to the acquisition of knowledge. These include bandwidth limitations such as Galileo's 10-20 bits per second, issues of line of sight radio transmissions, coordination of science results from multiple instruments on multiple platforms, and lack of any known benchmarks to tie our measurements to. Of particular importance is the ratio of science data volume to downlink bandwidth. As instruments get more sophisticated, the science data volume grows much faster than the bandwidth and swamps the data links. For example, the Shuttle Radar Topography Mission mapped over 90% of the Earth's land surface at one meter intervals. This produced over 200 Terabytes of data, feasible only because it was in low Earth orbit. The total surface area of Mars is comparable to the land area of the Earth so the data volume for a similar resolution mapping mission would be about the same. However, the distance from Earth to Mars is so large that the available bandwidth is only a fraction and it would take years to downlink the data for study on Earth.

The third and fourth dimensions are also being studied. The Tropospheric Emissions Spectrometer instrument will be launched soon to make three-dimensional maps of a variety of constituents in the Earth's atmosphere over time. While nowhere near one meter resolution, the volume of data is still prodigious. When you recognize that the entire planet Earth could be dropped into a large storm on Jupiter, volumetric visualization of the gas giant planet atmospheres becomes very challenging. Part of the response to these issues is to move more science analysis and processing out to the spacecraft. Automated analysis and feature recognition becomes necessary in order to find the interesting data in the flood. However, there is a tradeoff as automated algorithms can only do what they are told to do and a human's insight is necessary to make the major leaps.

Visualization tools are also gaining an increasing role in mission planning. For the upcoming Mars Exploration Rover missions, three-dimensional modelling and visualization of the environment is necessary to optimize the rover's activities within a limited lifetime. Here, multi-modal views of the rover, the local terrain, command sequences under construction, previous activities and results, and a host of other data must be presented to the operators to understand the local environment for effective mission planning.

The panelists will discuss these issues and how we are addressing them through such efforts as the Interplanetary Internet and mission operations systems for upcoming Mars missions, as well as where we need to go from here. In particular, the panel will close the loop from collecting data to downlink to visualization to mission planning to uplink of new mission activities and plans. The constraints that deep space operations put on data processing and visualization will be emphasized.

Position Statements

Rene Pischel

The High Resolution Stereo Camera (HRSC) is one of the major instruments on the European Mars Express Mission (MEX) which will reach Mars by the end of this year. We expect 3D data of unprecedented resolution and accuracy. The foremost appeal of these data is the fact that it will show the Martian surface in stereo

and in color. Visualization techniques will be used in two main directions:
1) for the scientists directly involved in the HRSC experiment (e.g. for planning, for data analysis like 3D viewing of geologic objects, calculation of volumes of valleys etc.)
2) for the public to create a "you are there" feeling using 3D techniques (movies, still pictures)
Many of the planned visualization techniques have been already proven with Earth remote sensing data acquired by an airborne version of the HRSC. In addition to classical 3D presentation techniques (anaglyphes, perspective views, gypsum models based on 3D data, 3D animated movies) we also tested new methods like computer screens and hard copy printouts allowing stereo vision without red/green or polarization glasses. Our Institute for Planetary Exploration hosts a visualization laboratory with special hardware for stereo presentations (e.g. stereo slide and overhead projectors).

Makoto Maruya

MUSES-C is a sample return mission to an asteroid, conducted by the Institute of Space and Astronautical Science in Japan. In deep space, it is difficult to navigate, guide, and control a spacecraft remotely from the earth on a real-time basis mainly due to communication delay and the bandwidth limitations. Thus autonomous navigation and guidance is required for the final approach to an unknown body, and the detailed information on the shape of the target body must be known in advance for such autonomous control. In order to create a model of the target asteroid, the MUSES-C spacecraft will capture the asteroid images from a stable position about 10-15 Km away from the target. The images will be transmitted to Earth, and the mapping will be performed by analyzing these images. Success of autonomous navigation depends on the accuracy of the 3D mapping.

Of course, the asteroid mapping must be visualized. A 3D viewer is available that enables users to see 3D terrain and annotated data from arbitrary view points. This was originally designed as Geographical Information System to display the information on Earth, but it has sufficient potential to integrate and display the information for other planets and asteroids. The viewer would be used to find the landing points, to mark scientifically interesting points, and also used as a communication tool.

Scott Burleigh

Visualization technologies need raw data to operate on. The deep space missions currently being planned will generate plenty of data, but conveying data at high rates from deep space instruments to visualization software on Earth is difficult for several reasons, some less obvious than others. Interplanetary distances are so vast, imposing such lengthy delays on data propagation even at the speed of light, that the conversational, interactive communicat Earth.ion model we live by in telephony and on the Internet must be set aside. Frequent and lengthy lapses in connectivity, due to both orbital motion and mission constraints, further retard bidirectional information exchange. What makes more sense is a "postal" communication paradigm in which even virtual circuit switching is supplanted by store-and-forward message switching.

Yet as the number and variety of deep space data sources increases, and as relay assets are deployed to improve their performance, the operational complexity of the emerging "Interplanetary Internet" will grow exponentially; today's labor-intensive hands-on management of space communication episodes will become increasingly impractical. What will be needed is a set of automated protocols that are functionally analogous to the network and transport protocols of the Internet but quite different in design and implementation. JPL is heavily involved in the articulation of a new "Delay-Tolerant Networking" architecture that will be applicable not only to the Interplanetary Internet problem but also to a variety of surprisingly similar communication challenges on Earth.

John Wright

One of the key steps in visualizing terrains is building the models. While challenging on Earth, attempting to build terrain models of other planets typically poses additional hurdles. For example, you cannot take a theodolite out and measure the locations of objects to calibrate the instruments. There is no GPS system available to locate the spacecraft. Even though an extensive calibration of the instruments is done prior to launch, the landing adds a few bounces to all the onboard equipment. There is often a requirement to merge data from multiple missions and instruments into a single, coherent dataset. For example, the rover might not be able to see behind a rock but an image was captured during descent that shows this hidden area and that data is desired in the terrain model. Of course the resulting models must be detailed and accurate since they are used to plan rover operations. A failure to identify and locate a hazard in the terrain could result in failure of the mission.

The Mars Exploration Rovers carry a plethora of stereo imagers. Some are primarily science instruments while others are primarily for navigation. These instruments produce different resolution models even when observing the same object from the same location.

A body of work has emerged concerning registering and merging models. These have usually involved a single sensor carefully moved between observations and thus have simpler calibration, merging, and verification issues but many of the techniques, such as Iterative Closest Points algorithms for registration and Marching Triangles for meshing, are applicable to the multiresolution arena. These are being applied to Mars terrain data in support of the Mars Exploration Rover missions but many challenges remain.

Scott Maxwell

Driving a Mars rover presents challenges not found in any Earth environment. One of the most serious of these is the lengthy light-time delay, which influences everything about rover driving. Instead of straightforward real-time remote control (often called "joysticking"), the driving model must be plan-and-wait: visualize the rover in a virtual environment constructed from the previous day's telemetry, plan its motion within this terrain, send the commands, and then wait for the next day's telemetry to see what happened. Because each day's planning time, like the rovers' lifetimes, is quite limited, the visualization and simulation must be fast and highly accurate -- we haven't a minute to lose!