A Space Systems Perspective of Graphics Simulation Integration

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Abstract

Creation of an interactive display environment can expose issues in system design and operation not apparent from nongraphics development approaches. Large amounts of information can be presented in a short period of time. Processes can be simulated and observed before committing resources. In addition, changes in the economics of computing have enabled broader graphics usage beyond traditional engineering and design into integrated telerobotics and Artificial Intelligence (AI) applications.

The highly integrated nature of space operations often tend to rely upon visually intensive man-machine communication to ensure success. Graphics simulation activities at the Mission Planning and Analysis Division (MPAD) of NASA's Johnson Space Center are focusing on the evaluation of a wide variety of graphical analysis within the context of present and future space operations.

~~This paper will describe~~ several telerobotics and AI applications studies utilizing graphical simulation. The presentation ~~will~~ include portions of videotape illustrating technology developments involving: 1) coordinated manned maneuvering unit and remote manipulator system operations, 2) a helmet mounted display system, and 3) an automated rendezvous application utilizing expert system and voice input/output technology.

MPAD Technology Overview

Achieving automated space operations capabilities requires the identification of enhancing and enabling technologies. A major challenge is dealing with the extensive integration required at multiple levels, programmatic phases and across program lines. This integration must be addressed early on and in parallel to allow efficient and cost-effective implementation. Examples of the integrated nature of operations across levels include:

1) Integration of vehicle systems and operations: Allocation of command and control authority between ground-based and/or space-based operations;

2) Determination of degree of automation: both ground and onboard for various systems;

3) Determination of capabilities required to automate functions: speed, parallel, realtime, expert systems, etc.

The wide range of possible configurations and implementation approaches dictates an integrated software systems strategy. Such a strategy is key to successful progress through the many stages of technology applicational readiness.

At MPAD, activities are supported by in-place laboratories and testbeds for expert systems technologies, graphics research, robotics software systems, rendezvous/proxops software, and vision systems software.

The expert systems technologies testbed is an extensive AI lab with proven experience in developing expert systems. Primary emphasis is placed on expert systems hardware and software evaluation and application development. The robotics software system testbed laboratory has the objective to understand computing, communication and control capabilities for coordinated robotic manipulation in space. The testbed environment will include robot/end-effector hardware, vision development, collision avoidance and path planning software. Collision avoidance studies are being done at MIT and path planning work at the University of Michigan and JPL. The rendezvous/proxops software testbed supports investigations of automated rendezvous and proximity operations with closed loop guidance, targeting, and control via an automated sequencer. The system has multi-vehicle, realtime simulation capabilities with 6 degree of freedom equations of motion and high fidelity subsystem models. The vision systems software simulation lab consists of hardware and software facilities at Rice University. Current and pending research includes low and intermediate level vision studies.

Graphics Research Laboratory

The graphics research laboratory provides capabilities for simulation and animation of space vehicles and robotics operations. The configuration of the graphics laboratory is illustrated in figure 1. The laboratory evaluates a wide variety of state-of-the-art graphics hardware and software. General applications include:

- Crew Training;
- Development of intelligent graphics software supporting system interconnection and user friendly, menu driven interfaces;
- Modeling of diverse and complicated vehicles;
- Expert systems/graphics lab interfaces and applications for development of advanced information communications;
- Applications for robotic manipulators;
- Development of high fidelity graphics systems to augment and/or replace operator line-of-sight television requirements;
- Graphics hardware and software state-of-the-art enhancements;
- Mission simulations and demonstrations for satellite rendezvous, close-in separation and contact, cargo transfer, manipulator operations, coordinated robotics activity, and communications.
- Analytical support to Mission Design and Development, and Guidance and Navigation branches at Johnson.

The following sections of this paper will now describe three integrated applications utilizing graphical simulation which illustrates some of MPAD's capabilities.

Coordinated MMU and RMS Operations

Two training simulators used in tandem to rehearse joint mission activities require communication or "talk" between one another. Presently in the MPAD graphics lab, an operator of a remote manipulator arm (RMS) simulator can observe on a television screen the flight of a manned maneuvering unit (MMU) being simulated across the room.

The MMU (a backpack worn by an astronaut to maneuver outside the space shuttle) is seen to move around the remote manipulator arm screen as it flies around in the field of view. Thus, astronauts on the space station, for example, who are assigned a new task of repairing a satellite using both the RMS (used to grapple payloads or serve as an astronaut platform) and the MMU backpack, could rehearse the mission together in a coordinated manner.

A prototype of this simulator project was completed in 1986 and integrated into the existing graphics laboratory facility. Upcoming plans call for a system designed for a unique application to be built around the prototype design. Its applications are not limited to the space station and has the potential for a wide range of uses.

Helmet Mounted Display System

MPAD is developing a low cost 3-dimensional helmet simulator for a variety of applications, particularly space station and rehearsal of satellite rescue and repair missions. The system, shown in figure 2 presents a line segment picture to a pilot or astronaut wearing the unit that changes with head movement. The helmet mounted display system provides new and improved ways of looking at 3-dimensional data as applied to flight simulation and other applications. Compared to non-movable graphics displays the helmet mounted display offers several advantages, most important of which being the ability to surround the viewer with an artificially generated geometric scenario that is truly 3-dimensional and stereographic.

Transformation and associated graphics subsystems were developed in the MPAD graphics lab and are connected to the system. Joysticks and helmet positioning devices form the interactive input to the system. The numerical hardware processes the input and computes the visual scene. Feedback is passed on to the output hardware which consists of a pair of miniature video monitors mounted directly on the helmet.

The fixed displays will soon be replaced by stereo displays, with a resultant increase in visual realism. Efforts are underway to replace the stick figures by developing specialized computer hardware to generate real-time shaded images. Later, artificial image generation will be combined with real-world video to further enhance the system.

There is a wide range of applications that could benefit from replacing stationary displays with helmet mounted displays. Telepresence servicing and flight simulation are only a few examples where the visual feedback can be enhanced by an order of magnitude. For instance consider simulating operations from within the space station cupola structure. Instead of building a physically large frame with five full size monitors, the helmet mounted display system would provide better realisim with just two miniature monitors. The image generation hardware would now only have to compute two images in realtime instead of five. In addition, there would be no need for physical construction of the cupola structure since it could be simulated in software together with the rest of the space station. Replacing table-top windows into the simulated scene by a stereo pair of moving windows can in effect project the operator into the artificially generated geometric scenario in every sense of the word, opening a new dimension in simulation realism and analysis capabilities.

Automated Rendezvous Expert System

The Rendezvous Expert (RENEX) system was developed to demonstrate the concept of using an expert system to perform autonomous rendezvous and proximity operations onboard a space vehicle during flight. The effort was motivated by the need to streamline operations for the space shuttle and space station programs as well as to provide insight into the mission requirements for greater autonomy during rendezvous operations in Earth orbit and Mars Sample Return and Comet Nucleus Sample Return unmanned missions.

The system consists of three basic components: 1) an expert system which controls the overall system by sending trajectory sequencing commands to and receiving feedback data from 2) a software simulation of space vehicles in orbit which calculates realtime trajectory data and sends trajectory information to 3) a graphics system for display.

One of the project goals was to develop technology which was transferrable to various types of trajectory control software to support future NASA projects, i.e., ground premission planning, ground realtime planning and monitoring, and onboard planning and monitoring. The technology can be incorporated into ground software to aid ground flight planners and controllers, or into onboard software to aid crewpersons and provide greater manned vehicle autonomy. It can also be integrated into appropriate planning and monitoring functions in onboard software to provide automatic operations for either manned or unmanned vehicles.

An example of a technology integration spinoff is depicted in the augmented RENEX system configuration shown in figure 3. A voice interface was connected which allowed voice commands to be used to override the automatic trajectory planning capability. Another potential spinoff involves demonstrating an automated capability to monitor the trajectories of spacecraft detached from the space station. Such a system could simulate man-in-the-loop telerobotic control of, for instance, an orbital maneuvering vehicle (OMV) being flown to a space station berthing area. A modified RENEX system could monitor the trajectory and system health conditions and update station crew operator(s) on trajectory and safety conditions. Among the achievable benefits of automating and assisting monitoring tasks would be reductions in crew workloads.

Summary

Identifying enhancing and enabling technologies for automated space operations necessitates the focusing of technology and advanced development activities. Plans implemented in evolutionary, building-block approaches must encompass research, simulations, advanced development, and demonstrations. Critical to success is integration. Utilization of a broad range of graphics tools provides for:

- identification of hardware and software enabling and enhancing technology requirements,

- evaluation of hardware/software designs,

- identification of effective command and control approaches,

- performance of hardware and software tradeoffs between alternative operational confirgurations.

Graphics capabilities, together with artificial intelligence and simulation tools, provide a technology base upon which to assess incremental progress in achieving autonomy objectives and for estimating the incremental cost of greater autonomous capabilities for space systems. One of the most important advantages is that it allows us to progress from fully man controlled operations to the appropriate degree of autonomy in an evolutionary, planned, controlled, and well understood progression.

Figure 1 - Graphics Laboratory Hardware Configuration

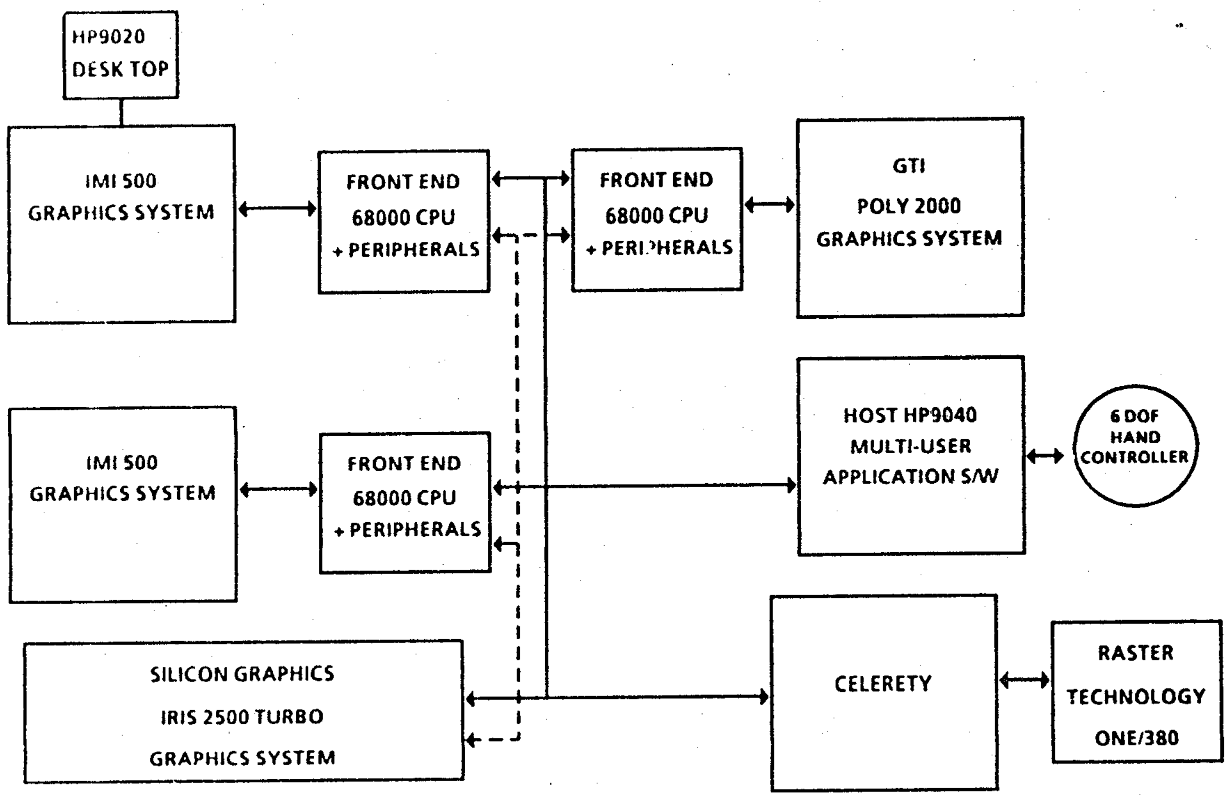

Figure 2 - Helmet-Mounted Display System

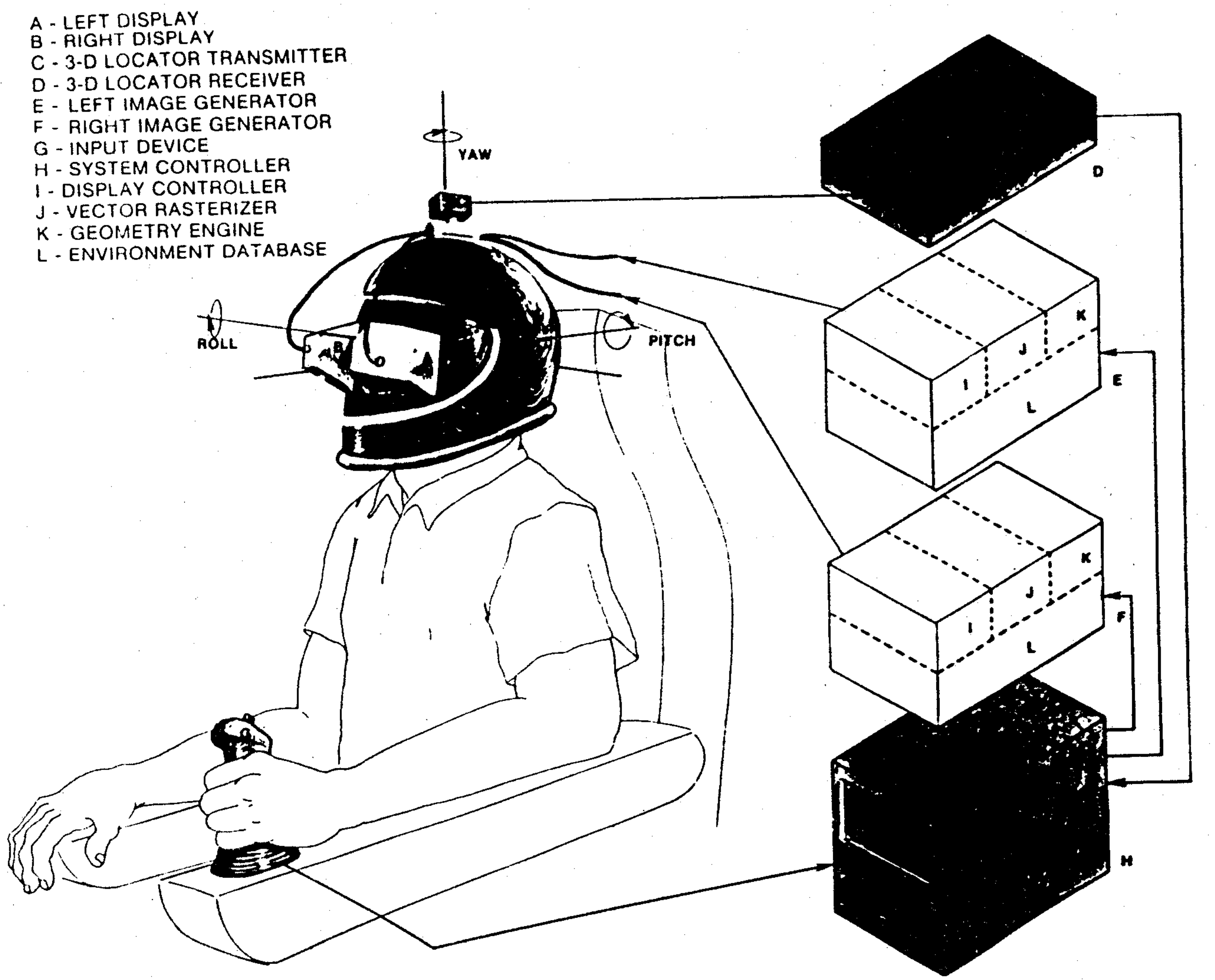

Figure 3 - RENEX System Configuration With Voice Interface