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COMPUTATIONAL CONTROLS WORKSTATION: ALGORITHMS AND HARDWARE

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ABSTRACT

The Computational Controls Workstation provides an integrated environment for the modeling, simulation and analysis of Space Station dynamics and control. Using highly efficient computational algorithms combined with a fast parallel processing architecture, the workstation makes real-time simulation of flexible body models of the Space Station possible. A consistent, user-friendly interface and state-of-the-art post-processing options are combined with powerful analysis tools and model databases to provide users with a complete environment for Space Station dynamics and control analysis. The software tools available include a solid modeler, graphical data entry tool, O(n) algorithm-based multi flexible body simulation and 2D/3D post-processors. This paper describes the architecture of the workstation while a companion paper describes performance and user perspectives.

Computational Controls Workstation: Algorithms and Hardware

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Hardware Architecture

The system hardware is designed around a special-purpose parallel processing architecture based on four Intel i860 processors. The parallel processor communicates with the host system through a standard VME bus interface. All user interaction is handled by the host, a Silicon Graphics Personal Iris workstation. A dedicated graphics engine on the host is used for the animator and solid modeler. Network access (Ethernet) and disk I/O is also handled by the host. The parallel processor is capable of sustaining over 40 double precision MFLOPS when used with the simulation software. Inter-processor communication is accomplished through message passing. This architecture is shown in Figure 1.

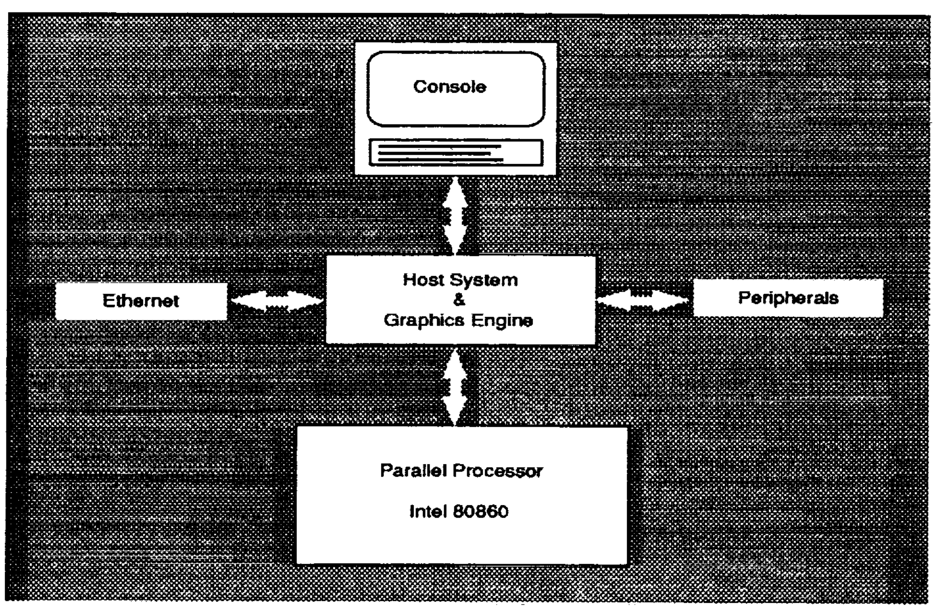

Figure 1: Workstation Hardware Architecture

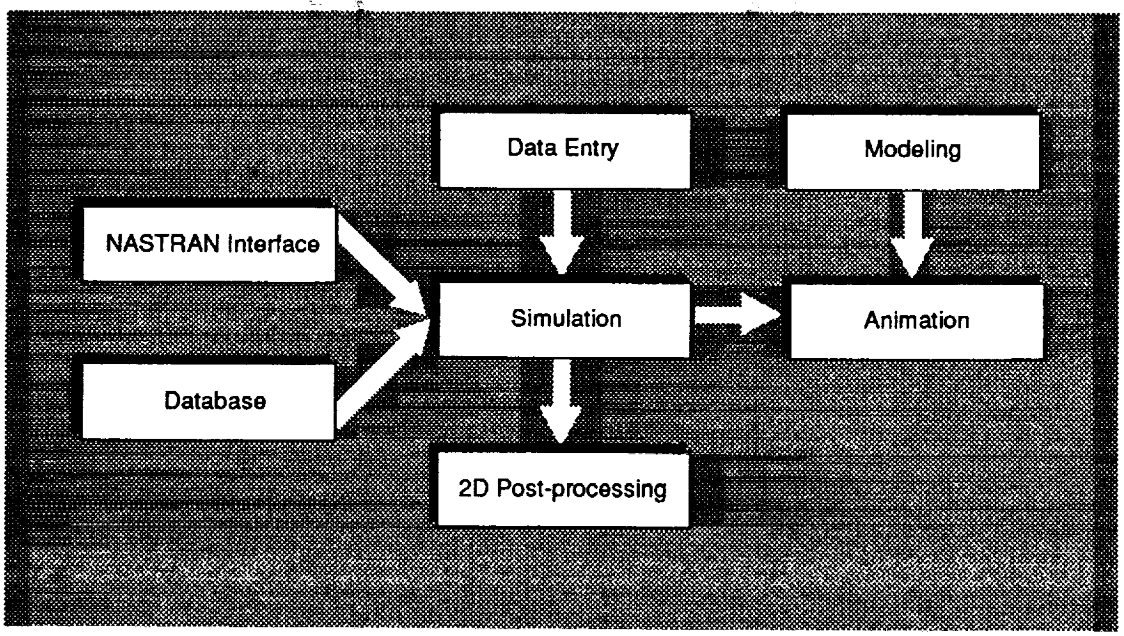

Figure 2: Workstation Software Architecture

Software Tools

The workstation prototype includes a set of integrated software tools that interact with the user through a consistent graphical user interface. They are:

- A window and mouse based interface for configuration data entry and modification
- A 3D solid modeling tool for geometry definition
- A full featured multi flexible body dynamics simulation package
- A 3D graphics animation package for the visualization of simulation results
- A 2D post-processing package for x-y plots
- An interface to NASTRAN for flexible body model data
- A database of typical Space Station configuration models

The software architecture is shown in Figure 2.

Data entry

The window and mouse based interface is built around an interactive screen editor for the creation and modification of configuration data. Up to three different data files may be edited at once, with facilities for copying and moving data elements between them. Data entry and editing is based on the concept of *forms* for each logical component (bodies, joints, sensors etc.) with full screen editing capabilities using the mouse and keyboard. Data is stored in files compatible with other tools that may require it.

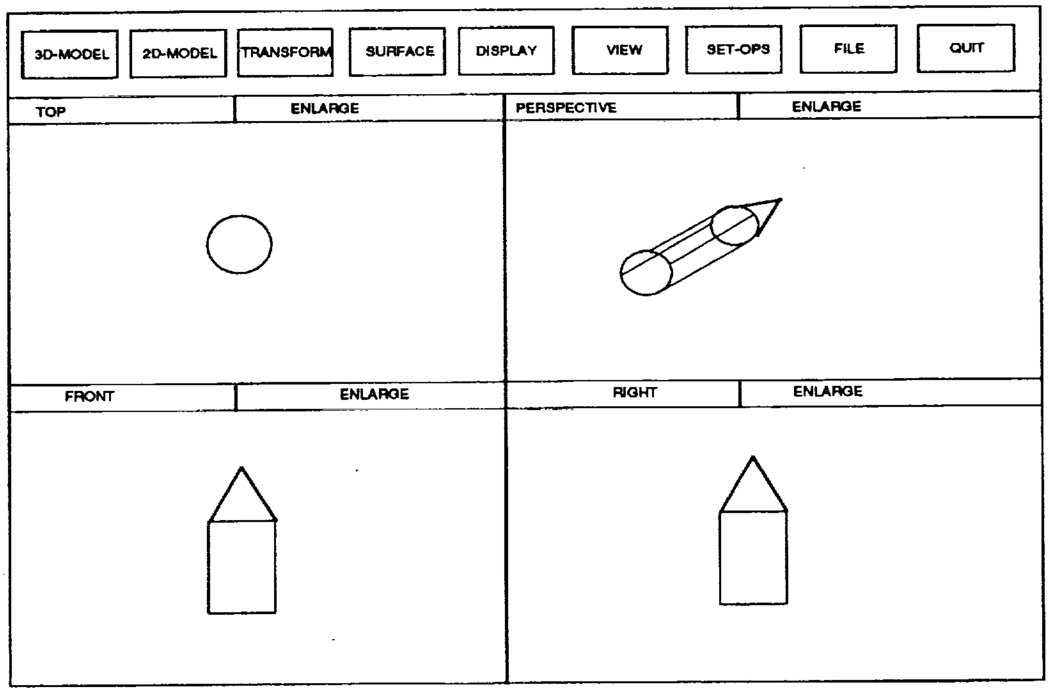

Figure 3: Solid Modeler Interface

Solid modeler

The 3D solid modeler is a simple, intuitive tool for creating, editing and storing graphical models for use in the animation facility. Using simple graphical primitives such as lines, curves, cubes, cylinders etc., the geometry of each sub-structure may be built and stored. Simple transformations (rotation, scaling) as well as complex ones (splining, extrusion, revolution, patching) help the user create highly realistic geometric representations. Wire-frame as well as solid models may be displayed, with special lighting and material effects. Several graphical objects may then be combined to form one simulation object (or body). The user interface to the modeling tool is shown in Figure 3.

Simulation

The multi flexible body simulation package represents a quantum leap in simulation technology. It uses an $O(n)$ algorithm for the solution of the dynamical equations. The equations of motion for the structure are processed by an artificial intelligence based symbolic manipulator that exploits the specific simplifications applicable to each configuration. The equations are then layered, scalarized and further simplified, producing highly optimized source code which is then compiled and linked to produce the simulation module. The simulation includes a set of built-in sensors and actuators as well as an interface for user-defined controller software. Typical RCS and CMG

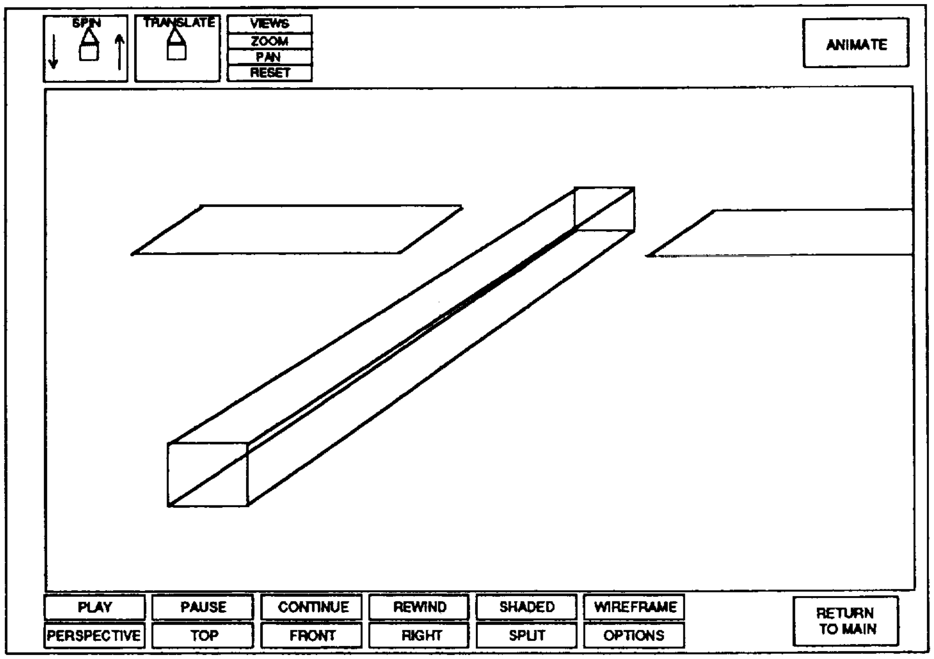

Figure 4: Animator Interface

controllers are included as part of the Space Station configuration database. Disturbances such as gravity gradient and aerodynamic drag are also modeled. The simulation software generated by the symbolic processor also includes automatic parallelization directives that split the simulation core into separate modules for concurrent execution on the four processors contained in the parallel processing hardware. Parallelization and parallel execution proceeds in a manner that is transparent to the user.

Animation

The animation tool combines the geometric data from the modeler with the simulation results to produce a 3D graphics animation of the movement of the multi-body structure. Four different viewing options (top, front right and perspective) are provided, with a choice of wire-frame or shaded drawings. The animation can be played in forward or reverse sequence, or paused at any instant for closer examination using a zoom function. The user interface to the animator is shown in Figure 4.

2D Post-processing

Standard x-y plots of simulation results can be produced using the 2D post-processor. Sophisticated features such as scaling, multiple input plots, multiple frames and phase plane plots can be invoked. The package can be configured for hardcopies on *Postscript* and *hpgl* devices.

NASTRAN Interface

The NASTRAN interface program reads data from MSC or COSMIC NASTRAN runs and computes the integrals required in the simulation program. Using efficient computational algorithms and direct access files, the program can handle large finite element models without prohibitive memory and computational requirements.

Configuration database

A database of Space Station configurations, starting from the first element launch to assembly complete will be made available. The database will also include the applicable controllers and will be updated as the configurations evolve.

Extensions

A number of extensions and additions to the basic concept are planned. These enhancements will be made on an ongoing basis, and made available to users periodically. The solid modeler and animation facility will be extended for more complex operations. Facilities to import previously defined graphical models in industry-standard formats (IGES, etc.) will be provided. This will allow users to import solid models from several finite element pre-processors. The parallel processor will be enhanced to provide standard language constructs that can then be used to execute user-defined software concurrently.

A host of additional software tools are currently being examined for porting to the workstation. These include finite-element programs, linear analysis tools, linearization tools, model reduction tools and modern control design tools. The new tools will be implemented maintaining the smooth, transparent flow of data between them, an idea that will remain central to the workstation concept.

The Space Station configuration database will also be updated as new designs of the structure and control systems evolve. In addition, other Space Station subsystems such as the Mobile Servicing Center (MSC) may be added, along with their associated control elements. A database of sensors and actuators is also planned, that will allow the user to efficiently compare responses. Finally, the database could include an expert system interface that will provide assistance in areas such as component selection and placement, modeling, model reduction and control design. Additional modeling features are also planned, including models of the orbiter, the shuttle RMS and berthing operations. This will provide the first integrated simulation of the Space Station dynamics, attitude control, berthing and de-berthing and MSC operations.

The workstation concept is not limited to Space Station configurations, and can be used for general multi flexible body modeling, simulation and control design. All the interfaces are designed for maximum flexibility, thus minimizing migration time.

References

1. Roithmayr, C.M., Straube, T.M. and Tave, J.S., "Computational Control Workstation: Algorithms and Hardware", *Proceedings of the 5th Annual Conference on Aerospace Computational Control*, NASA-JPL, Aug. 1992.