

A Virtual Space Environment Simulation System

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Abstract. Visiting the outer space freely was the human imagination until recently. Virtual environments of the space will be the way for people to “visit” the space to study their motion and interrelationships. This paper assembles a scalable, immersive virtual environment system called the Virtual Space Environment Simulation System (VSESS) that allows users to visualize objects and physical phenomena in near-earth space and provides a brief sketch of the design thinking of such system. The software architecture of the VSESS is designed incorporate the various simulation, analysis and visualization elements of the system into a single, integrated environment. The system employs a VR system with double projector to build immense 3-D environment and applied to some actual space projects and they demonstrate the efficacy of the concept and the processing.

Keywords: space system, virtual simulation, virtual space environment, VR.

1 Introduction

Until very recently, visiting the outer space freely was the human imagination - a notoriously poor form of transport. The variety, complexity, size, and in outer space conspire against using just the mind to comprehend the motion of satellites, other physical phenomena in outer space, and their interplay. For example, because of the complexities of orbital motion, examining the orbital elements for even a few spacecrafts does not provide an understanding of the positional relationships of the spacecrafts or of the motion of the bodies involved.

Unfortunately, people cannot look to space flight to provide insight, much less the ability to partake of the outer space’s wonders - the time when a common person can visit the outer space freely lies in the distant future. Even when outer space travel becomes possible, the cost required will preclude visiting more than a few planets. We believe that, for the foreseeable future, virtual environments of the space that are based on orbital motion information and accurately portray each body’s appearance will be the only - and most illuminating - way for people to “visit” the space to study their motion and interrelationships.

On the other hand, because of the cost and in many cases the unfeasibility of simulating spacecraft missions in a terrestrial environment, computer based simulation systems are a possible alternative. As graphics techniques for photo-realistic visual simulation have evolved over the last ten years it is now possible to simulate scenes of high complexity. Simulation systems using advanced visualization techniques can be

used for applications such as mission planning and rehearsal. Such systems allow alternative mission scenarios to be explored for modest cost and no risk. Another important use of the visual simulation software is to provide a tool for generating mission concepts to a wider audience. A visual simulation which can be understood at a glance will often generate the enthusiasm and advocacy which words alone cannot achieve [1].

Several systems have been developed to promote insight into selected aspects of orbital spacecrafts' relationships and appearance [2~6], but they provide a limited solution. We therefore assembled a more complete scalable, immersive virtual environment system called the Virtual Space Environment Simulation System (VSESS) that allows its user to visualize objects and physical phenomena in near-earth space.

We undertook the VSESS project to improve comprehension and appreciation of the complexity, motion, and splendor of near-earth space. To do so, the VSESS must (1) accurately portray the orbital behavior of satellites, planets, and other bodies, and (2) function in a virtual environment. Additionally, the system needs to

- provide a flexible, 3D graphical user interface for immersive operation, graphically model all bodies in near-space in 3D and to the same scale;
- accurately portray the objects and their locations;
- provide analytical capability and visualization of results, and
- maintain an interactive frame rate.

In this article we describe how we met these requirements.

2 Architecture Overview

The software architecture of the VSESS is designed incorporate the various simulation, analysis and visualization elements of the system into a single, integrated environment. Fig.1 shows the major software modules of VSESS and their interrelationships.

There are six primary software modules and a database which comprise the VSESS. The six software modules are (1) Simulation Controller, (2) Scenario Manager, (3) Space Objects Simulator, (4) Space Environment Simulator, (5) Analysis Module, and (6) 3D Display Engine. The database is The Satellites Orbit Database.

The Simulation Controller is responsible for controlling the whole simulation process while running. The Scenario Manager Module has two main functions: (1) Objects Manager. This module deals with all kinds of objects in the simulation scenario including space-base objects and ground-base objects. We can easily add, delete, modify and operate any object through this module; and (2) Time Manager. By using the Time Manager, user can set start, end time and time step for simulation and can also make time speed up or speed down freely. Time can be animated forward, reverse and in real-time to simulation.

Space Objects Simulator is one of the core sub-systems in VSESS. It provides multiple analytical and numerical propagators (Two-body, J2, J4, SGP4) to compute satellite position data in a wide variety of coordinate types and systems. For the novice, Space Objects Simulator provides the Orbit Wizard to guide the user through

quick creation of commonly-used orbit types such as geostationary, circular, critically-inclined, sun synchronous, molniya, and retrograde. For ground-base objects, this module also has the ability to calculate their position and velocity for analysis, visualization.

The Space Environment Simulator provides the capability of numerical calculation for the basic space environment elements such as atmosphere, Magnetosphere, Ionosphere, and etc.

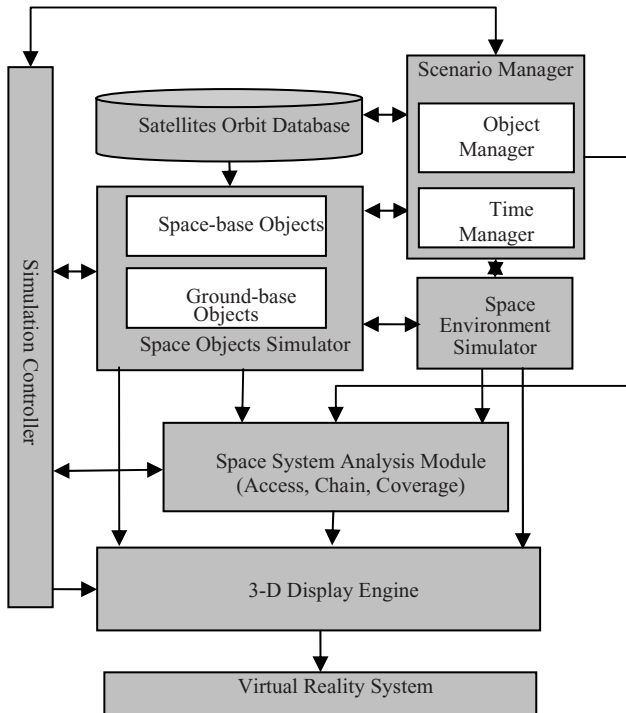


Fig. 1. Major Software Modules & Their Interrelationships

The Space System Analysis Module is another core sub-system in VSESS. It has the ability of access, chain and coverage analysis. VSESS allows user to determine the times one object can see, another object. In addition, user can impose constraints on accesses between objects to define what constitutes a valid access. The Chain module allows users to extend the pair-wise analysis capabilities to include accesses to and from satellite constellations, ground station networks, groups of targets and multiple sensors. The Coverage module allows user to analyze the global or regional coverage provided by a single satellite or a constellation of satellites while considering all access constraints. Specific results are generated based on detailed access computations performed to grid points within an area of coverage.

The last important module is the 3D Display Engine. This Display Engine brings 3-D viewing capability to the VSESS environment. This engine takes advantage of

today's readily available workstations graphics engines to provide state-of-the-art interactive graphics performance. It displays all near-earth space information from VSESS using realistic and dynamic 3-D views of space, airborne and terrestrial as-sets, space environment, and orbit trajectories.

The only database in VSESS is the Satellite Orbit Database. This database uses the STK satellite database as its data source. STK satellite database is available on its web site (www.STK.com) and updated every week. The most extensive database, from which all of our other databases are derived, is an up-to-date catalogue of over 8,000 objects. This database is maintained by U.S. Space Command. It contains data on Two-Line Element sets (TLEs), Space Surveillance Catalog (SSC) numbers, common names for satellites, launch dates, launch times, apogee, perigee, activity state and more.

3 Objects of VSESS

Objects are the building blocks of a VSESS simulation scenario. Platforms in VSESS include satellites, grounds stations, airplanes, ships as well as earth, moon and sun. Fig. 2 contains the objects diagram for the VSESS.

We build the space system using object-oriented methodology. The basic space object types – Space base and Ground base objects, Sphere (celestial bodies) and Stars – are all derived from the Space-object, which is the root object for the system.

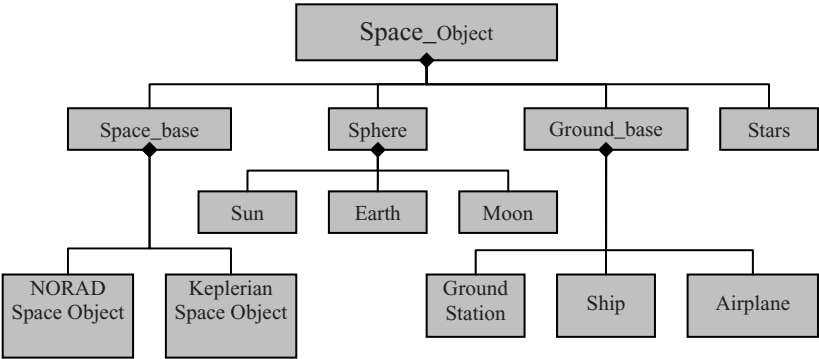


Fig. 2. Object Definition

The sun, moon and earth objects are derived from the Sphere object. The Earth object is considered to be at the origin of the VSESS and the magnitude of its position is always zero. The physical constants describing the Earth include mass, mean equatorial radius, flattening coefficient and rotational rate. The Sun and Moon objects are internally predefined and the user has limited control over their initial conditions. They are propagated using algorithms based on general perturbation theory as described in [7]. The propagation modules are accurate enough to allow modeling of solar and lunar eclipses.

The NORAD Space Object defines circular or elliptical orbits about the earth by using the NORAD SGP4 or SDP4 orbit propagators, while the keplerian space object also defines orbits by using analytical and numerical propagators (Two-body, J2, J4, etc.)

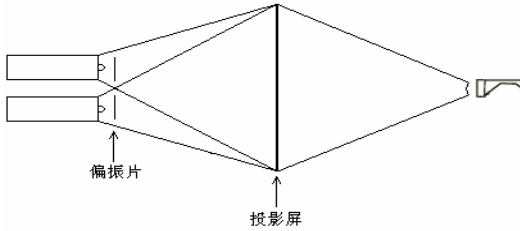


Fig. 3. VR system of VSESS



Fig. 4. Projectors of the VR system

4 System Implementation

We built the A Virtual Space Environment Simulation System using object-oriented methodology on the system of Windows XP based on the design way given in this paper. All modules were written in C++ with Microsoft Visual C++ 6.0. We employ a simple VR system (shown in Fig. 3) with double projector to build immense 3-D environment, Fig. 4 shows the projectors of the VR system. The software uses 3-D view to make all the information of the result of simulation and analysis visible. The 3-D view were developed by using OpenGL API functions and achieve a frame rate of between 40 and 60 frames per second depending on the number of satellites being propagated

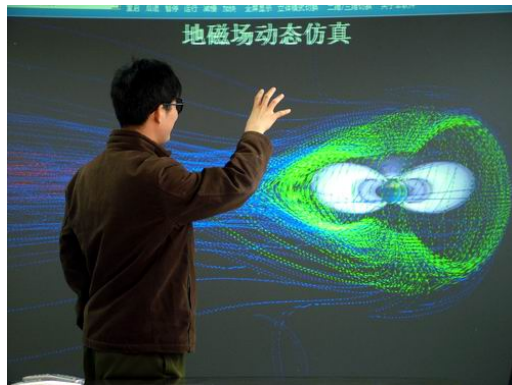


Fig. 5. Visible Magnetosphere in VR system

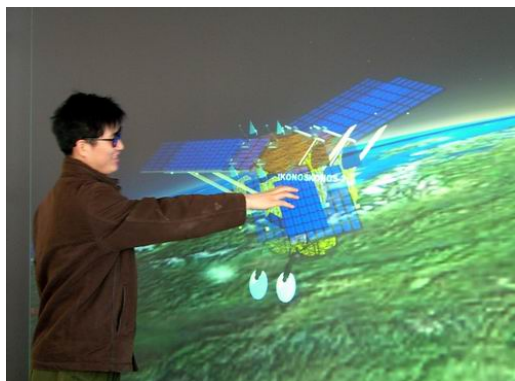


Fig. 6. Spacecraft simulation in VR system

and their orbits in our VR system. Fig. 5 shows the visible magnetosphere in our VR system. Fig. 6 presents spacecraft simulation on orbit, and a 3-D view of a close-up satellite's model, Earth surface and the result of sensors simulation. Earth texture and colors are based on NASA data and images from Planetary Arts and Sciences.

5 Conclusion and Future Work

VR tools and computer simulation can play an important role in the field of space designs and applications. The simulation techniques with advanced scene generation technology and analysis capability can produce new tools with applications in mission planning, rehearsal and presentation. The purpose of the design of VSESS is to provide near-earth space environment simulation and analysis system and decision makers with intuitive insight involving the near-Earth astro-dynamics problem domain. This paper provides a brief sketch of the design thinking of such software. The system we developed is applied to some actual space projects and they demonstrate the efficacy of the concept and the processing.

We plan to expand the software in several ways. First, we intent to improve the analysis capability of space system. We also intend to model and simulate the near earth space environment and then develop a capability to compute the effect of satellite in space environment in VR environment.

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