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A Simulation and Modeling Framework for Space Situational Awareness

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ABSTRACT

This paper describes the development and initial demonstration of a new, integrated modeling and simulation framework, encompassing the space situational awareness enterprise, for quantitatively assessing the benefit of specific sensor systems, technologies and data analysis techniques. The framework is based on a flexible, scalable architecture to enable efficient, physics-based simulation of the current SSA enterprise, and to accommodate future advancements in SSA systems. In particular, the code is designed to take advantage of massively parallel computer systems available, for example, at Lawrence Livermore National Laboratory. The details of the modeling and simulation framework are described, including hydrodynamic models of satellite intercept and debris generation, orbital propagation algorithms, radar cross section calculations, optical brightness calculations, generic radar system models, generic optical system models, specific Space Surveillance Network models, object detection algorithms, orbit determination algorithms, and visualization tools. The use of this integrated simulation and modeling framework on a specific scenario involving space debris is demonstrated.

1. INTRODUCTION

Lawrence Livermore National Laboratory (LLNL) applies forefront science and technology to anticipate, innovate and deliver responsive solutions to complex global security needs. LLNL is currently working with other National Labs (LANL, SNL, AFRL) to apply forefront science and technology to improve space situational awareness. LLNL is developing a comprehensive framework for modeling, simulation and visualization of space situational awareness. This framework, called the Test-bed Environment for Space Situational Awareness (TESSA), employs a parallel discrete event simulation architecture and utilizes high performance computing infrastructure. This enables (1) simulating the orbit of hundreds of thousands of objects, (2) physics-based modeling of sensor performance, (3) scalable visualization in an interactive environment. The organization of TESSA across multiple computer platforms is shown in Fig. 1.

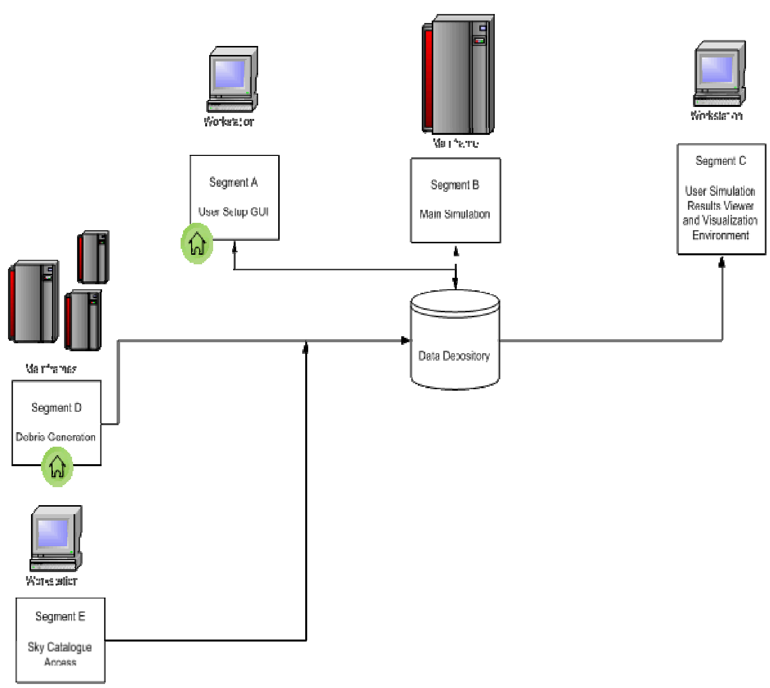


Fig. 1. Test-bed Environment for Space Situational Awareness: organization across multiple computer platforms

TESSA employs a modular approach for simulation features. Modules include hydrocode-based intercept debris generation, detailed orbital modeling, generalized radar model, generalized optical model, Space Surveillance Network model, sensor scheduling, orbit determination, visualization.

2. TESSA ARCHITECTURE

Fig, 2 shows the TESSA architecture. This is a conservative parallel discrete event simulation. Discrete event means that state changes are all discontinuous, not continuous. Conservative means that the sycnhronization is done without rollback.

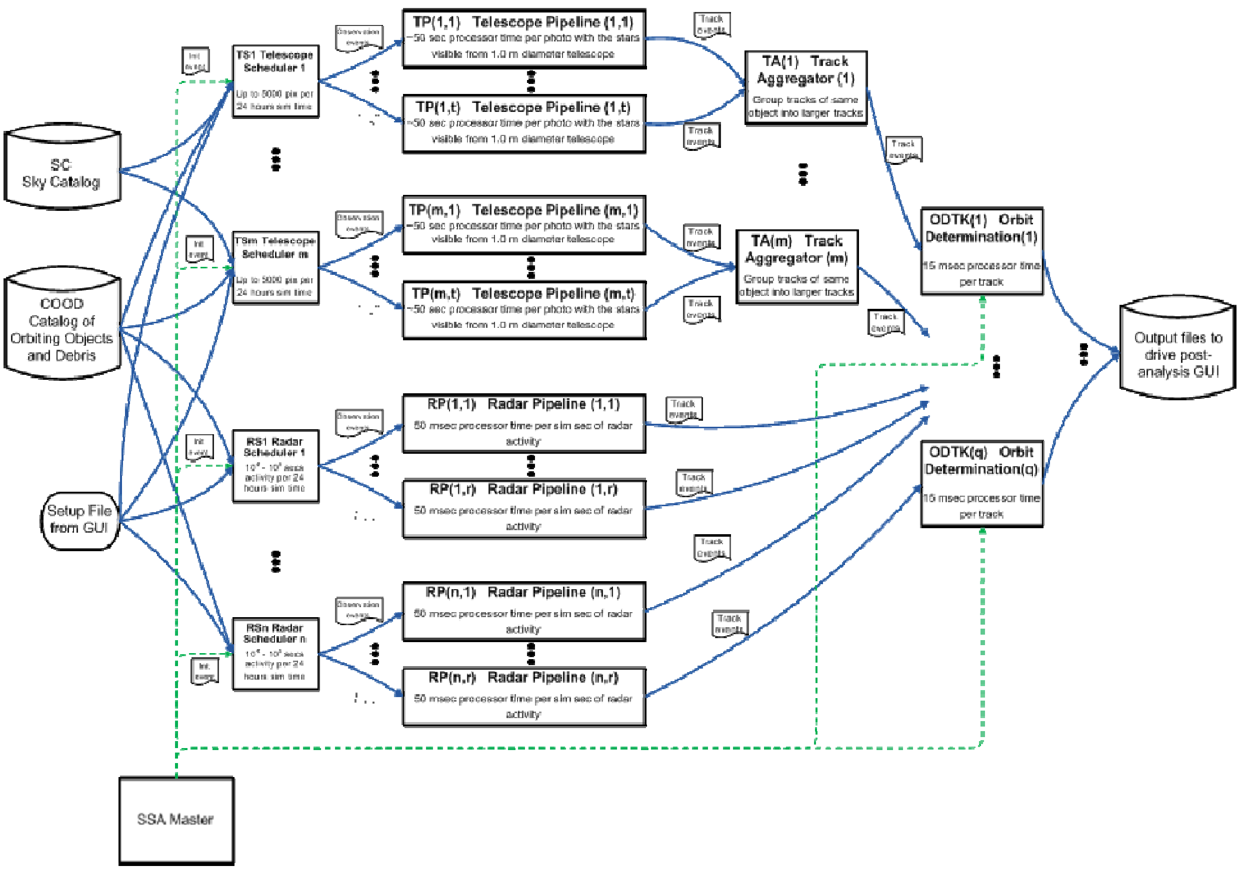


Fig. 2. TESSA architecture

3. INTERCEPT DEBRIS GENERATION

Modeling of hypervelocity impact and resulting debris generation is performed using PARADYNE, a parallel version of DYNA 3-d with an advanced, anisotropic fragmentation model. This code has been validated using light gas gun and sled track ground truth data. An example of the output from this code is shown in Fig. 3.

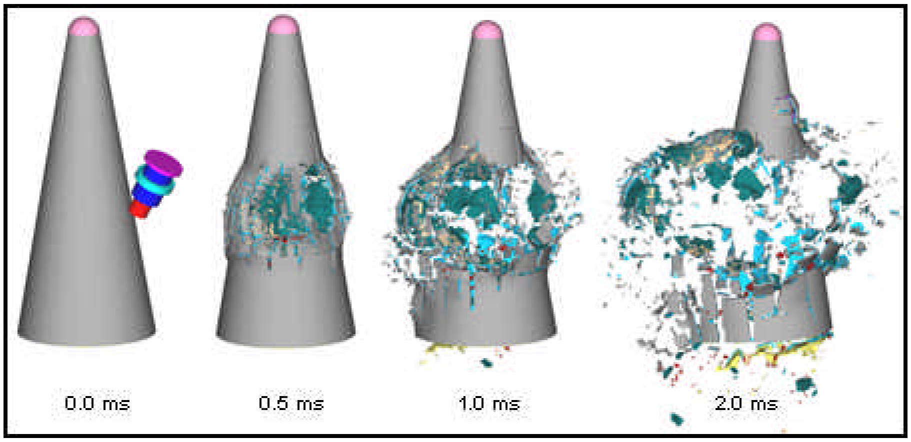


Fig. 3. Hydrocode intercept simulation

4. ORBITAL MODELING

Orbital propagation is computed using a standard propagator, SGP4 (November 2007 update), or using a force model when higher accuracy is needed. Force models use either the JGM-3 or EGM-96 geopotential model and include solid body tides without resonance terms, sun and moon third body perturbations, along with Venus, Mars, and Jupiter third body perturbations. Different atmospheric models may be used, including Harris-Priester, NRL-MSISE-90, NRL-MSISE-2000, GOST 84, GOST 2004, Jacchia-Roberts 1971. The 1980 IAU 108 term Earth nutation model is used, as well as the IAU Earth precession model, and the ICRF inertial coordinates (J2000). Additional effects include solar radiation pressure, cylindrical or dual cone umbra and penumbra.

5. GENERALIZED RADAR MODEL

The radar detections are performed using detailed models of radar cross sections, and radar system parameters.

6. GENERALIZED OPTICAL MODEL

The optical detections are performed using detailed models of optical brightness and telescope system parmeters. A simulated optical image is shown in Fig. 4.

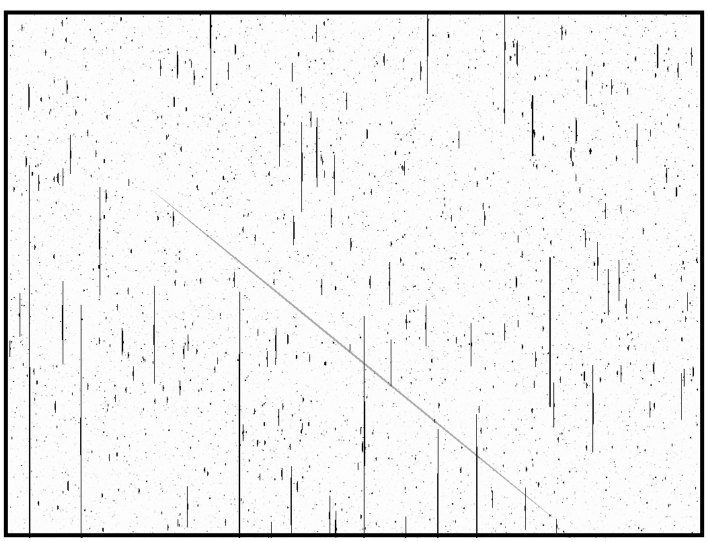


Fig. 4. Simulated optical image

7. ORBIT DETERMINATION

Orbit determination is performed using the following steps:

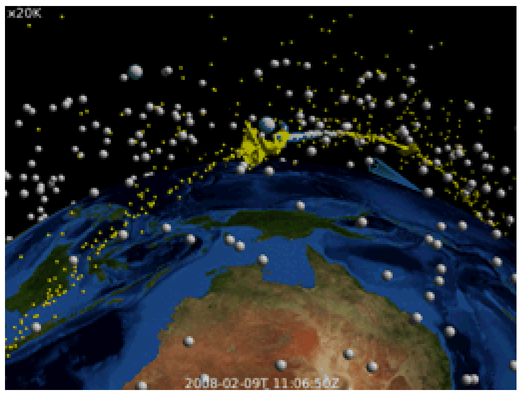
1) First orbit determination
2) Orbit refinement using batch least squares
3) Follow orbit evolution due to unmodeled forces with the Extended Kalman Filter

8. VISUALIZATION

An effective visualization system for SSA enables one to:

1) Browse and navigate large amounts of data
2) Provide real-time rendering of the simulation data
3) Allow interactive queries and simulation feedbacks

An example of our visualization environment is shown in Fig. 5.



9. FUTURE WORK

Furture work will involve incorporating and validating the SSN sensor and scheduling models (collaboration with ESC, AFSPC/A9, AFRL/HPCC), as well as implementing specific new sensor models and analyzing scenario-dependent system performance enhancement.

10. ACKNOWLEDGEMENT

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