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Parallel satellite orbital situational problems solver for space missions design and control

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Abstract

Solving different scientific problems for space applications demands implementation of observations, measurements or realization of active experiments during time intervals in which specific geometric and physical conditions are fulfilled. The solving of situational problems for determination of these time intervals when the satellite instruments work optimally is a very important part of all activities on every stage of preparation and realization of space missions.

The elaboration of universal, flexible and robust approach for situation analysis, which is easily portable toward new satellite missions, is significant for reduction of missions' preparation times and costs.

Every situation problem could be based on one or more situation conditions. Simultaneously solving different kinds of situation problems based on different number and types of situational conditions, each one of them satisfied on different segments of satellite orbit requires irregular calculations.

Three formal approaches are presented. First one is related to situation problems description that allows achieving flexibility in situation problem assembling and presentation in computer memory. The second formal approach is connected with developing of situation problem solver organized as processor that executes specific code for every particular situational condition. The third formal approach is related to solver parallelization utilizing threads and dynamic scheduling based on "pool of threads" abstraction and ensures a good load balance.

The developed situation problems solver is intended for incorporation in the frames of multi-physics multi-satellite space mission's design and simulation tools.

Keywords: Space mission design; Situation analysis; Orbital events

1. Introduction

The question "where and when along the satellite orbits instruments are configured for science data acquiring and optimal scientific task solving" has exclusive significance for optimal, quick and low cost space mission preparation.

The analysis of different events related to satellite orbits aims at solving of particular sub-problems during the basic phases of space missions: concept exploration, research, development and operation (Vallado, 2007). Mission concept exploration allows to achieve orbital parameter optimization using obtained scientific data from the first phase. The planning of the use of particular resources (spacecrafts, service subsystems and scientific instruments) aims at optimal parameters selection in the second phase. Scheduling all satellite and ground based activities requires determination of time intervals during which their execution is possible in the mission operation phase.

The implementation of satellite operations is possible under specific constraining conditions related to visibility and illumination of investigated objects or environmental parameters. The analysis of theses conditions over time is

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known as situation analysis (Prokhorenko, 1983a). Different constraints which are analyzed have geometrical (angles, distances) or physical (illumination of objects, intensities of vector or scalar fields and their derivatives calculated by models, densities or energies of particles, radiation situation) nature. The conditions could be connected with active experiment simulations for calculation and evaluation of constraining parameters.

Prokhorenko (1983a, 1985) has emphasized the importance of the situation analysis for preparation of space missions in the field of magnetosphere investigations. The possibilities for analysis using parallel data acquisition in the frame of different space missions for joined processing and interpretation are pointed in (Nazirov and Prokhorenko, 1996, 1998; Prokhorenko et al., 1998; Nazirov et al., 2002; Frey et al., 1989).

Different approaches for situation analysis were developed in the past. Prokhorenko (1983b) originate orbital tori method and different application for space mission analysis (Prokhorenko, 1983a, 1985).

Another example for situation analysis developed in the past is related to determination of "come in" and "come out" satellite times and positions according to Earth shadow (Escobal, 1965; Mullins, 1991). This approach is based on analytical solution of two body problem and Kepler's equation. Many authors treated this problem in different aspects related to the numerical solution of the equation of Earth shadow (Eremenko, 1965; Longo and Rickman, 1995; Neta and Vallado, 1998; Zhang and Cao, 2001).

Atanasov (1992) proposed generalized method for situation analysis based on transformation of situation condition toward Kepler's plane. This approach can be applied to different relatively static or dynamic geometrically defined situation conditions. In (Atanassov, 2003) application of this approach to situation condition treating passing of satellite over moving circular region of Earth's surface was shown. This method was applied (Atanassov, 2009) to magnetosphere situation problem – intersection of satellite orbits with magnetopause/bow shock. These semi-analytical approaches are applicable to one orbit revolution and are very effective.

Other approach for situation analysis is based on "step by step" calculations of the satellite coordinates by using different geometrical and physical parameters. All of these quantities are included in checking of specific conditions based on constraints. This situation analysis approach is more powerful and gives more possibilities for realization of complex calculations with high fidelity of results for each case. This approach was applied in the past to treat planning of multi-satellite magnetosphere mission (Prokhorenko, 1985; Gogoshev et al., 1985). Such approach was applied to analysis of possibilities for implementation of astrophysical measurements on board of Mir station (Gaidarov et al., 1989).

Specific situation problem, which importance increased lately, is the so called "orbital conjunction". An approach based on Kepler's orbits is effectively used for special filters which separate potentially dangerous events (Hoots et al., 1984). Approaches based on numerical integration of orbits are developed because of accuracy and stability of the solution. Parallel distributed calculations related to orbit propagation, by the both analytical and numerical methods, were developed and investigated (Lustman et al., 1991, 1992; Neta et al., 1994). Coppola et al., 2009 developed parallel algorithms to speed up calculations to handle the increasing number of objects on orbits around the Earth.

Wertz and Larson (1999) emphasize that applied mission analysis algorithms must be simple and effective enough to allow making multiple runs, allowing collecting statistical data and explore various scenarios and design options. The development of effective tools for situation analysis is very important in the case of heavy multi-situation problems solving, each including more than one situation conditions.

Concept and development of parallel situation problem solver is presented in this article. Additionally, we explain in some details situation problem description model and numerical solution. A solver developed for multiple situation problems solving, using multiple situation conditions is presented as well. The concept of solver parallelization is described.

The rest of the paper is organized as follows: The second section explains the essence of situation analysis and the necessity of parallel calculations application. Section 3 treats situation problems description model; Situation problems solver is presented in Sections 4 and 5 presents shortly some auxiliary subroutine which are necessary for facilitation situation processor application; The performance of the processor is estimated in Section 6; Some discussions are presented in Sections 7 and 8 concludes the article and indicates some possible developments and applications.

2. Problem statement

2.1. Situation problem

Each orbital situation event can be presented in the general case by a predicate function S:

$$S = S(\vec{R}, A, t) = \overline{0,1} \qquad (1)$$

In (1) $\{\vec{R}\} = \langle \vec{r}_1(t), \vec{r}_2(t), \ldots, \vec{r}_n(t) \rangle$ is set of the radii-vectors of the objects in the model space, $\{A\} = \langle \alpha_1(t), \alpha_2(t), \ldots, \alpha_m(t) \rangle$-set of vector or scalar fields, describing certain properties of the model space and t – the time.

Actually, we can have a combination of several constraining conditions for one situation problem. In addition, we shall examine such conditions that are independent from each other. Thus, the set of situation conditions $\{\gamma_i\}$ can be juxtaposed to the set of predicate functions $\{s_i\}$.

The presence of situation event S will require the fulfillment of the following identity: