S E S 2 0 2 4
Twentieth Anniversary International Scientific Conference
SPACE, ECOLOGY, SAFETY
22 – 25 October 2024, Sofia, Bulgaria

AN APPLICATION OF SITUATIONAL ANALYSIS SOLVER IN SOLVING PROBLEMS RELATED TO SELF-SHADING OF SOLAR PANELS ON PLATFORMS WITH COMPLEX STRUCTURES

Atanas Atanassov

Space Research and Technology Institute – Bulgarian Academy of Sciences
e-mail: At_M_Atanassov@yahoo.com

Keywords: *solar array, satellite array self-shadowing, situational analysis*

Abstract: *Estimating the self-shading of solar panels by other satellite structural elements provides a more realistic view of the performance of satellite energy systems. Modelling tools are being developed for applying a Parallel Situation Solver in problems related to self-shading of satellite solar arrays.*

ИЗПОЛЗВАНЕ НА СИТУАЦИОНЕН АНАЛИЗ ПРИ РЕШАВАНЕ НА ЗАДАЧИ СВЪРЗАНИ СЪС САМОЗАСЕНЧВАНЕ НА СЛЪНЧЕВИ ПАНЕЛИ НА КОСМИЧЕСКИ ПЛАТФОРМИ СЪС СЛОЖНИ СТРУКТУРИ

Атанас Атанасов

Институт за космически изследвания и технологии – Българска академия на науките
e-mail: At_M_Atanassov@yahoo.com

Ключови думи: *слънчеви панели, само-засенчване на спътникови слънчеви панели, ситуационен анализ.*

Резюме: *Оценката на само-засенчването на слънчеви панели от други конструктивни спътникови елементи дава по реалистична представа за функционирането на енергийните системи на спътниците. Извършва се разработка на средства за моделиране, за прилагане на Паралелен Ситуационен Процесор при решаване на задачи свързани със само-засенчване на спътникови слънчеви панели.*

Introduction

When designing space missions, it is important to carry out a preliminary analysis of the feasibility of the planned tasks. This includes, first of all, an analysis of the possibilities for carrying out observations and measurements, related to the search for time intervals when suitable geometric and physical conditions are present. At the next stage, it is necessary to check the energy balance required for the operation of various subsystems and instruments [1, 2, 3, 4]. Solar panels are the basis of the energy systems of various classes of satellites. These panels convert solar energy into electricity depending on the size, technology used and orientation to the Sun. In addition, attention is paid to the self-shading of solar panels from satellite structural elements [1, 5]. In the movement of a satellite around the Earth, its orientation changes according to observed objects. This may cause some of its components to occlude the solar array. The underestimation of the self-shading of the panels from structural elements can lead to over-optimistic estimates for expected solar power generation.

Work is underway to develop a program environment for simulating space missions at the Space Research and Technology Institute of the Bulgarian Academy of Sciences. The Parallel Situational Analysis Solver [6] is among the computational tools developed for modelling and simulation. This solver is currently developed to solve problems of geometric character, related to the position of the Sun, the Moon, observed objects, and the satellite. Other elements of this environment are related to modelling tools and methods for simulating satellite energy systems based on solar panels [7]. Here we consider the possibility of implementing the situational solver, to solve problems related to the self-shading of solar panels by satellite structural components.

Modeling of satellite constructive elements

From a constructive point of view, satellites can be represented (with sufficient approximation) as being composed of geometric shapes such as spheres (or parts of spheres), cylinders, cones (or truncated cones), or regular polyhedra (with rectangular lateral walls). Solar panels can be installed on lateral satellite walls or as separate rectangular sections, either fixed or by dynamic suspension. Some of the geometric shapes (sphere, cylinder or cone) represent second degree surfaces (quadrics). Quadrics are defined by equation of second degree [8 Выготский]

(1) $Ax^2 + By^2 + Cz^2 + Dxy + Eyz + Fxz + Gx + Hy + Kz + L = 0$

Solar panels can be represented as rectangles located in planes with a specified orientation relative to the satellite. This plane can be defined by its normal vector $\vec{n}$ and a fixed point $\vec{r}^*$ in the satellite coordinate system.

(2) $\vec{n}\,.(\vec{r} - \vec{r}^*) = 0$

Each structural satellite elements is described by a geometric shape with specific attributes, the

```
! Derived type for module shape description
    type  mod_shape                                                    (a)
      integer  shape_type
      real*8   x0,y0,z0
     union
      map      ! Sphere
        real*8   radius1
!           other parameters
      end map  ! Sphere
      map      ! Cylinder
        real*8   radius2,hight2
!           other parameters
      end map ! Cilinder
  end union
 end type  mod_shape

    type     sat_platform
     union
      map                              ! Only for processing control
        integer     num_modules        ! a number of structural elements of satellite
        real*4      distance           ! Distance to the satellite model
        real*4      light_source_pos(3) ! The position of the light source
        real*4      light_source_power
      end map
      map
        type (mod_shape) sat_module
      end map
     end union
 end type sat_platform

USE module_name
  type (sat_platform)   satellite(0:max_num_modules,num_sat)           (b)
```

Fig. 1. Derived type for shapes description (a); using the derived type

values of which are presented by a derived type. A satellite structure descriptor is represented by a one-dimensional array, each element of which refers to a separate satellite structural element (Fig. 1a). The null element of the array contains information about the entire satellite. A two-dimensional array is used for the satellites of a multi-satellite mission (Figure 1b).

A dialogue tool (satellite constructor) is under development to model the shape of a satellite composed of elements with the above-mentioned shapes. A descriptor is created for each satellite to control the panel's self-shading calculations. Within the framework of modelling the shape of the satellite, an actual situational solver is created to solve the self-shadowing task.

Organization of PV cells in a solar array

The PV cells are the basic units of a PV arrays. Multiple cells are connected in series to form PV modules. The modules can be connected in series or in parallel in array according to the desired output parameters (the necessary current and voltage values) [9]. The modules in a PV array are first connected in series to obtain the desired voltage; after that, the individual strings are connected in parallel to produce more current.

Self-shading by structural satellite elements is one of the possible reasons for energy loss in PV arrays. Even the shading of one cell of m - cell module can reduce the power output significantly. This is due to the high internal resistance of the p-n junction in the cell crystal in the absence of light.

Self-shadowing as a situational problem

To solve the task of self-shading of the PV-cells by the solar panels, the coordinates of the Sun are necessary. They are calculated using a special subroutine [10] in the Geo-Equatorial coordinate system (GEcs). After that, the coordinates from GEx must be transformed into the satellite's topocentric coordinate system [11]. Finally, the coordinates are transformed into the satellite's coordinate system, depending on its stabilization and orientation in space. The orientation of the "agile" satellites can be changed to observe targets located on the Earth's surface or the celestial sphere.

After transforming the Sun's radius vector into the satellite's coordinate system, checks are performed regarding direct "visibility" from each separate element of the solar panel. It is checked whether the straight line connecting each separate PV cell of the panel to the Sun (assumed to a first approximation for a point object) crosses any of the structural elements of the satellite. This approach is known as "ray tracing" [12–15]. The development of subroutines for checking situational conditions related to various geometric shapes is in progress.

Radiation reduction on separate cells is possible if we consider the sun as a disc with angular dimensions and calculate the shading caused by satellite components. The energy produced by the PV panel can be corrected in this way.

Conclusion and future work

An application of situational analysis when analyzing the self-shading of satellite solar arrays is proposed in the report. The application of the developed parallel situational solver is appropriate given the high dimensionality of the tasks being solved. It is expected that analyses of the influence of self-shading in complex satellite constructions, solar panels of significant sizes and multi-satellite missions can be performed due to the efficiency of the solver. The efficiency of the solver is based on both the application of parallel calculations and optimization methods of situational analysis.

References:

1. Fincannon, H. J., 1995. Analysis of shadowing effects on spacecraft power systems. In *European Space Power Conference* (No. NAS 1.15: 106994).
2. Куренков, В.И., Салмин, В.В. and Абрамов, Б.А., 2007. Моделирование целевого функционирования космических аппаратов наблюдения с учетом энергобаланса. *Самара:[Изд-во СГАУ]*.
3. Patel, M.R., 2004. *Spacecraft power systems*. CRC press.
4. Chen, Q., Liu, Z., Zhang, X. and Zhu, L., 2020. *Spacecraft Power System Technologies*. Springer Singapore.
5. Куренков, В. И. and Пупков, Е. А. , 2023. Модели для определения ориентации солнечной батареи космического аппарата наблюдения относительно Солнца при объектовой съёмке и перенацеливании. *Вестник Самарского университета. Аэрокосмическая техника, технологии и машиностроение*, *22*(3), pp. 47–58.
6. Atanassov, A.M., 2016. Parallel satellite orbital situational problems solver for space missions design and control. *Advances in Space Research*, *58*(9), pp. 1819–1826.
7. Atanassov, A. and L. Atanasova, 2021. DEVELOPMENT OF TOOLS FOR COMPUTER MODELING AND SIMULATION OF SATELLITE ENERGY SUBSYSTEM FUNCTIONING. In Proceedings of Conference "Space, Ecology, Safety", pp. 81–87; Available on: http://space.bas.bg/SES/archive/SES%202021_DOKLADI/1_Space%20Physics/12_Atanassov.pdf
8. Выготский, М. Я., 1975. Справочник по высшей математике, М, сс. 872.
9. Bhatia, A, Design and Sizing of Solar Photovoltaic Systems; Available on: https://www.cedengineering.com/userfiles/R08-002%20-%20Design%20and%20Sizing%20of%20Solar%20Photovoltaic%20Systems%20-%20US.pdfhttps://www.cedengineering.com/userfiles/R08-002%20-%20Design%20and%20Sizing%20of%20Solar%20Photovoltaic%20Systems%20-%20US.pdf
10. Vallado, D. A., 1991. Methods of Astrodynamics, a Computer Approach.
11. Эскобал, П., 1970. Методы определения орбит: Пер. с англ. М., „Мир".
12. Glassner, A. S. ed., 1989. *An introduction to ray tracing*. Morgan Kaufmann. Avalaible on: https://www.cs.cmu.edu/Groups/fox/people/fp/ /cmu- courses/graphics only/ray1.pdf
13. Ji, X., Zhang, Y., Li, X., Fan, G. and Li, M., 2019. Solar ray collection rate fluctuation analysis with Monte Carlo Ray Tracing method for space solar power satellite. *Solar Energy*, *185*, pp. 235–244.
14. Kenneally, P.W. and Schaub, H., 2020. Fast spacecraft solar radiation pressure modeling by ray tracing on graphics processing unit. *Advances in Space Research*, *65*(8), pp. 1951–1964.
15. Meng, X., Du, K., Bai, X., Mankins, J.C. and Liu, C., 2020. Numerical investigation on improvement of energy transfer in solar power satellite. *Renewable Energy*, *148*, pp. 103–112.