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DEVELOPMENT OF NEW FUNCTIONALITIES FOR A SPACE MISSIONS SIMULATION PROGRAM SYSTEM

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Abstract: *"**Observer**" has been developed - a module that provides 3D rendering of the dynamics of multiple satellites in terrestrial orbits. It is possible to launch two "observers" simultaneously, each with different parameters. The parameters of each "observer" are entered in a special dialog form. The parameters (observation point, viewing angle, coordinate system, size of the window) of each of the "observers" can be changed during the simulations.*

Complex of subroutines have been developed to generate "satellite constellations". The distribution of satellites is specific to this type of space missions – in several orbital planes with the same inclination, but with different arguments of ascending nodes, evenly spaced within the equatorial plane. The true anomalies are evenly distributed within each orbital plane with appropriate phase shift. The number of satellites and their orbital parameters are selected depending on the scientific or applied scientific tasks to be solved.

РАЗРАБОТКА НА НОВИ ФУНКЦИОНАЛНОСТИ КЪМ ПРОГРАМНА СИСТЕМА ЗА СИМУЛАЦИИ НА КОСМИЧЕСКИ МИСИИ

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Резюме: *Разработен е "Наблюдател" – модул, който осигурява 3D изобразяване на динамиката на множество спътници на около-земни орбити. Възможно е едновременно стартиране на два "наблюдателя", всеки от които е с различни параметри. Параметрите на всеки "наблюдател" се въвеждат от специална диалогова форма. Промяната на параметрите (точка на наблюдение, зрителен ъгъл, координатна система, размери на прозореца) на всеки от "наблюдателите" може да се извършва в хода на симулациите.*

Разработени са комплекс подпрограми за генериране на "спътникови съзвездия". За този тип космически мисии е характерно специфично разпределението на спътниците в няколко орбитални равнини с еднакво наклонение, но с различни аргументи на възходящите възли, равномерно разпределени в рамките на екваториалната равнина. В рамките на всяка от орбиталните равнини истинските аномалии са равномерно разпределени с подходящо фазово отместване. Броят на спътниците и орбиталните им параметри се подбират в зависимост от решаваните научни или научно-приложни задачи.

Introduction

Ideas for many-satellite (satellite constellations, spacecraft formation flying) experiments and their application are increased in the recent years. Advance in development of mini-satellite technology is also essential.

Complex space missions are being established on the base of conception of distributed satellite sensor systems [1, 2, 3, 4]. Such missions require the application of computer simulation based analysis and design methods. Complex multi-physics models and multi-solver applications multi-dimensional multi-parameter simulation experiments lead to the need of parallel calculations.

Previous work

Algorithms and calculation instruments for multi-satellite space mission design are under development in SRTI- BAS [5, 6]. The developed tools are included in experimental program system for space mission simulations [7]. So far, the software system has been able to simulate the dynamics of satellites in terrestrial orbits and to conduct situational analysis. Given the emerging new interesting problems related to the functional modeling of complex multi-satellite systems equipped with various service and scientific tools, there is a need for visualization in the course of simulations. Therefor tools have been developed to simulate an "observer", which shows in a window a model scene from the area where the experiment or measurement is being conducted.

Tools for modeling of satellite constellations and processes, related to the operation of service systems and scientific instruments have been developed in the last time/recently.

Development of “observer” type object

The development of an object of type "observer" is associated with the creation of a class with appropriate attributes, describing the object. A version of the class “observer” is shown on figure 1. The observer created a rectangular frame in which the observable objects are displayed. Objects of interest in terms of space mission design tasks are regions of Earth surface, satellites, and celestial objects. Appropriate calculations are required to display the objects in the observer’s window.

```
module
  type     Observer
    logical  Earth       ! To image (.true.) or not to image (.false.) the Earth.
    logical  satellites
    logical  Sky          ! To image (.true.) or not to image (.false.) the sky.
    integer  KS          ! 1- GeKS, 2- GrKS
    integer  fi,tita     ! fi- longitude and tita- latitude
    real*8   distance    ! distance to object
    real*8   l           ! coordinate of  “eye” of the observer in coordinate system

    union                ! parameters of the windows'
      map
        integer  width,high
      end map
      map
        integer  win(2)
      end map
    end union
  end type  Observer
end  module
```

Fig. 1. Some of the possible parameters of the „Observer“ class

Формиране на изображение на Земята

3D image of the Earth globe is calculated in the coordinate system of the observer. For this purpose, a 2D raster color image (such as in Fig. 2, right) is used to form the spherical image. The image is rendered on the observer window.

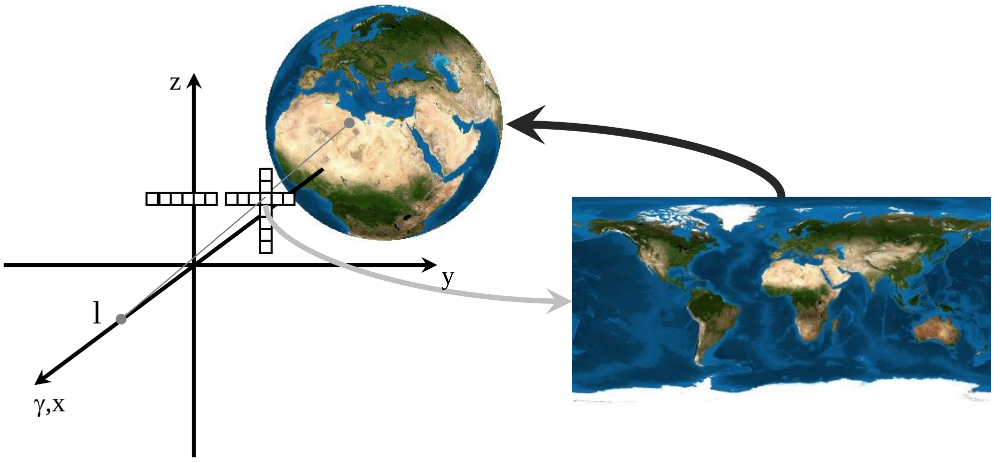

Fig. 2. Coordinates of pixels from Observer's window (m,n) determined direction of the viewing ray

The calculations of Earth's globe image are based on concept related to viewing rays, which intersects the sphere representing the Earth surface. The following equations system is used as mathematical model of this concept:

(1). $$\left\| \begin{array}{l} (x - C_E)^2 + y^2 + z^2 = {R_E}^2 \\ x = -x_0 + l.t \\ y = m.t \\ z = n.t \end{array} \right.$$

The first equation of system (1) defines a spherical surface with a center coinciding with the center of the Earth in the coordinate system of the observer and a radius equal to the average Earth's radius (R_E = 6371 km). The other three parametric equations determine the lines passing through two points, with coordinates (l, 0, 0) and (0, m, n) respectively (Fig. 1). Substituting x, y and z from the parametric equations in the first one and making possible transformations we obtain quadratic equation for parameter t:

(2). $$(l^2 + m^2 + n^2).t^2 - 2l.(l + C_E).t + \left((l + C_E)^2 - {R_E}^2\right) = 0.$$

By solving (2) we find the value of the parameter t. Returning to (1), we will find the points, where viewing ray intersects the Earth's surface, in the coordinate system of the observer. If the observer is in a geo-equatorial system (GeCS), the transformation in the part related to translation is only along the x axis. Furthermore, if the x-axis of the observer coordinate system does not coincide with the x-axis of GeCS, i.e. we have rotation of angle φ and we also have rotation of y-axis of angleλ, i.e. the observer is not in the plane of the equator and then two successive transformations are required:

(3). $$\left\| \begin{array}{l} x' = \ \ x.cos\varphi + z.sin\varphi \\ y' = \ \ y \\ z' = -x.sin\varphi + z.cos\varphi \end{array} \right. \quad \text{и} \quad \left\| \begin{array}{l} x'' = \ \ x'.cos\lambda + y'.sin\lambda \\ y'' = -x'.sin\lambda + y'.cos\lambda \\ z'' = \ \ z' \end{array} \right.$$

These transformations are sufficient for the Greenwich Coordinate System but for transformation in the Geo-Equatorial System, more transformations have to be added because of the Earth's rotation $\lambda = \lambda_0 + \omega_E.t$

Thus, the coordinates (x'', y'', z'') give the geographical coordinates of the corresponding point in the image of figure. 2. These coordinates determine the pixel of the 2D image that is displayed in the Observer window.

Simulation of satellite constellatios

Recently, there has been a growing interest of research, connected with capabilities of satellite constellations to solve remote sensing tasks on Earth and to study near-Earth space. The deployment of different sensors on satellite platforms, located in a specific way around the Earth, enables to collect information from many different points at the same moments. In addition, there are specific configurations that allow collection of information within limited time frames that is appropriate for some tasks.

Most constellations can be classified by one of the following categories [10]:

– Walker (Delta/star) pattern constellations,
– Streets-of-Coverage constellations,
– Geosynchronous constellations,
– Elliptical Orbit pattern constellations,
– Other constellations.

The use of templates facilitates generation of satellites constellation models and also prevented constellation design's errors. This approach allowed investigating and achieving the optimum number of satellites and their distribution for particular scientific tasks. The use of templates facilitates the generation of satellite constellations models and prevents design errors.

At this stage, a preliminary version of **Walker- Mozhaev** type constellation [8, 9] was developed. In this type of constellation, the orbits of the satellites are circular and distributed in several orbital planes. An image of such satellite constellation with 890 satellites distributed in 5 orbital planes is shown on Fig. 3. The semi-major axes are 7500 km, eccentricities e = 0.01 and inclinations I = 30 degrees, respectively.

The formation an image of a satellite constellation is important, because in addition to defining the model, it will mostly be applied in simulations to present a dynamic picture a representation of dynamics. Development of the "observer" object by adding an attribute that defines the possibility of "seeing" satellite objects. Similarly, other objects located on the celestial sphere or on the earth's surface can be added.

Fig. 3. Illustration of satellite constellation

The geometric model outlined above is used to display the satellites on the observer screen (there may be two "observers"). Here, the guide vector of strait lines passing through the "eye" of the observer (located in (l,0,0)) and the satellite is determined by the coordinates of the observation point (l,0,0) and the coordinates of the satellite in the coordinate system of the observer (x_{sat}', y_{sat}', z_{sat}'). Since the equations of motion of the satellites are in GeCS, the coordinates must be transformed into the coordinate system of the "observer". The transformations of (3) are used. Initially second transformation from (3) is applied for case of rotation around the z-axis.

Thus, if the line passing through the eye of the observer and the satellite does not pierce the sphere associated with the earth's surface, the satellites are "visible" and their pixel coordinates on the observer's screen (where they are to be displayed) are calculated. If the viewing ray intersects the sphere (two piercing points), there are options for the satellite to be behind the Earth and not visible, or it is in front of the Earth and should appear on its image. For this purpose, the distances from the observer's location to the piercing points of the viewing ray with the sphere representing the earth's surface are determined. The distance to the satellite is compared to the distance to the nearest piercing point.

Parallelization of visualization algorithms in the Observer window

For more efficient use of computing resources (if more than one processor is available), the visualization of objects seen by one or two "observers" is computed based on parallelization. One thread is used for each observer. The performed experiments used the "union of pools" model [11], which in addition to pools of calculation threads can work with individual calculation threads. In this case, one pool of threads will be engaged with trajectory calculations of satellite constellation and two threads for rendering the two Observer's windows containing the Earth was combined in one "union of pools".

Another computation experiment was also conducted in which all calculations for visualization of the satellites of the simulated constellation for the two "Observers" were combined with other calculations. In this case calculations were performed within individual computational thread in second "union of pools". Thus, two unions of pools functioned in this example.

Conclusion and future work

The approach with use the "Observer" can be applied to simulate measurements with optical instruments when designing remote observations on the Earth's surface, in addition to presented illustration of the geometry of space experiments. In this case, an "Observer"-type object is created for each optical instrument with certain parameters (viewing angle, field of view containing a certain number of pixels) on the basis of which an image is formed. Different images can be rendered on the base of the generated data from optical instruments located on different satellites, when simulate measurements in the frame of distributed sensor mission.

Developed set of algorithms and subroutines related to Walker type satellite constellation composition will be extended to cover and other type of multi-satellite systems.

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