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Concept of group debris cleaning using unmanned servicing spacecraft

A concept of an approach to the debris cleaning using a group of servicing spacecraft to provide reliable navigation and efficiency. Some of the results of mathematical modelling are provided.

Group debris cleaning

Despite the recognition of the global problem of combating contamination of near-Earth space, debris cleaning technology is in the initial stage of development. Thus as part of TeSeR program, which was presented in May 2016, the task was placed to create the prototype tools, which allow to safely remove any out of order spacecraft from orbit. The test phase should begin in 2018 [1].

Federal Space Agency ("Roskosmos") plans to launch a new spacecraft “Liquidator” into geostationary orbit of our planet in 2025, whose main task will be cleaning debris, consisting of out of order satellites, booster units and other left over parts from previous launches into space. Designing of the new spacecraft is scheduled to begin in 2018 [2].

US offer other countries to carry out joint massive cleaning of debris, after having developed the necessary technology [3].

The Navigation-ballistic provision (NBP) for servicing spacecraft (SC) occupies an important place in the process of cleaning of debris. During the design of NBP, the extensive scope of SSC application, as well as the tendency to the use of autonomous onboard systems on the base of satellite navigation should be taken into account.

In 2009 the European Space Agency estimated the number of near-Earth debris larger than 5 cm as 43 837 objects, about 20 % of which were on highly elliptical orbits [4].

The NBP for higher elliptical orbits for SC faces many problems. It is first of all the unstable radio navigation field. Therefore, significant time intervals may exist when there are no navigation satellites (NS) available for the use of SC.

There exist numerous approaches, which are based on changes in the composition and algorithmic support of onboard systems of SC, to solve this problem.

This paper proposes the concept of using a group of servicing SC to solve the problem of cleaning the debris in unstable radio navigation field.

Nowadays more and more attention is paid to the organization of group SC flights. Such SC groups may be used, for example, for forming large aperture antenna fields, sequential multi position recording of the Earth surface, etc. [5].

The concept of the group SC debris cleaning involves the following.

The group of servicing SC intended for the disposal of debris is centered in the chosen field of near-Earth space. The group should consist of at least four servicing SC. According to the terminology adopted in [5], each SC in the group may be a master or a follower. Each SC has its own satellite navigation equipment, means of communication with any other SC in the group, including the means to transmit its own coordinates, which are linked to the onboard time scale, as the master, or the receiving of them as a follower. Additionally, the format of the information about the coordinates during the transmission and reception has to be coordinated with the format of the navigation signal.

The orbits of the SC are selected and calculated in advance, in accordance with the debris disposal technology and orbits design theory [6, 7]. However, an additional requirement is imposed on the relative position of the SC in the group.

The position should be optimized to provide the navigation determination of SC group (with exchange of information) on longer sections of the orbital movement. To solve this problem, a methodology was developed, for example [8].

Conditions ensuring the navigation position determination in the group suggest that, at least two SC of the group must receive the information from four sources of navigation signals.

Possible options:

- One SC receives a signal from the three NS and signals broadcast from one other SC, which receive signals from sufficient number of NS for determining the position (option 1);

- One SC receives signals from two NS and signals broadcast from two other SC, which receive signals from sufficient number of NS for determining the position (option 2);

- One SC receives signals from one NS and signals broadcast from three other SC, which receive signals from sufficient number of NS for determining the position (option 3).

Mathematical modelling was used to test the concept.

The initial data are the coordinates of 6 NS, recorded with a navigation receiver at a fixed point in time, and given coordinates of the object.

Software complex provides:

- the generation of pseudo ranges with random error (normal distribution with set parameters - $m\xi, \sigma\xi$);

- the solution of the problem of determining the coordinates of the object on the one-step algorithm based on the method of least squares;

- obtaining the statistics of positioning errors by varying the number of satellites and standard deviations (SD) of errors during the generation of pseudo range.

Statistics were determined by averaging 1,000 iterations.

Table 1 shows the SD of spherical positioning error SP depending on the number of operating satellites (during which $m\xi := 0$ m, $\sigma\xi := 10$ m) and the geometrical dilution of precision GDOP, which correspond to the satellite configurations.

Table 1.

Results of mathematical modelling

Number of NS	SP, m	GDOP
4	65	6.6
5	26	2.7
6	22	2.35

In the case of broadcast of coordinates from the master SC to the follower SC, the corresponding pseudo ranges for navigation tasks are generated with a SD equal to SP.

Table 2 shows the SD of spherical error sp1, sp2, sp3 respectively for the three above specified options of the interaction of SC in the group.

Table 2.

Results of possible SC groups options modelling

SP, m	sp1, m	sp2, m	sp3, m
65	171	247	340
26	84	114	146
22	82	111	125

The results obtained in (Table 1, Table 2) reveal the following.

The efficiency of the supplement signal to follower SC depends substantially on GDOP of the navigation satellite constellation, which master SC uses.

By increasing the transmitted signals from 1 to 3 the follower SC navigation position determination error increases from 3 to 6 times compared with the master SC.

The obtained results do not deny the possibility of further development of the concept.

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