New Approaches to Organizing the Operation of the Space Surveillance Facilities

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At the present time one can observe an evident discrepancy between the current Space Surveillance System (SSS) scientific-technical base (which is overaged) and the high level of space surveillance tasks required by reality nowadays. The last events in space confirm this. In February 2009 for the first time in space activity history two large satellites (“Cosmos” and “Iridium”) collided in orbit. The event happened at the height of 800 km over Siberia.

The smallest cataloged space objects (SO) have the size 5 – 10 cm, while really dangerous for active spacecraft are space debris of size 1 cm and less. In 1996 French satellite “Cerise” dramatically collided with some Arian’s fragment. Space debris made a cavern about 4 mm in the porthole of the orbital station “Salute 7”. At the frontal window of one of “Challengers” a dent of 2.5 cm diameter and a half cm deep was found. After 4 years of orbiting of the US “Solar Max” some two thousand holes and dents were found in its heat-protective cover.

Accumulation of small SO is going on and our both SSS don’t cope with the function of informational provision for real time space activities.

There are two evident directions of perfecting the SSS:
- radical upgrading the space surveillance facilities (sensors, computing complexes, communication lines and so on),
- development of essentially new approaches to planning and controlling operation of the facilities. While the first direction in Russia, USA, Europe, Japan is being developed very actively, the second direction lags behind.

A possible way to overcome this blind alley consists in revising some approaches to organizing the operation of space surveillance facilities. As the base for this, one can use the new theoretical approach to optimum planning of the search for a given SO, taking into account temporal structure transformation of the SO current position uncertainty domain (CPUD). This theory was developed by S. S. Veniaminov [1, 2, 3, 5, 7]. Application of this theory is most effective for narrow-angle and narrow-beam facilities in the sense that it provides the most economy of their search resource, the detection of the sought for SO being guaranteed.

At present, the metric information on a SO is being supplied by radar and optical sensors affiliated with the SSS. This information is enough for representation of the general state of the space objects population. Special cases (for example close approaches) need much more precise metric information than that about smaller SOs or fainter signals. For this task narrow-angle and narrow-beam sensors are needed.

These sensors, if being used and controlled traditionally, can metrically maintain a very limited population of SOs. At the same time there are evident tendencies of growth of the number of small SOs that need precise metric information. So, essential perfection of ideology for operating the sensors is necessary.

When planning the search for a SO with the help of narrow-angle and narrow-beam sensors (in the case when all the SO CPUD cannot be covered with one field of view (FoV) of the sensor), there occurs a delusion. For constructing the search plan (SP) one usually does not take into account the real temporal structure transformation and deformation of the SO CPUD during its motion. The consequence of such a carelessness is a rise of errors of the 1st and 2nd kind - appearance of “chinks” between the SP elements, where one can lose the sought for SO (1st kind) and redundant overlapping between the adjacent SP elements implying non-economical expenditure of the sensor search resource.

For elimination of these errors a special theory of optimum planning of the search (TOPS) was developed [1, 2, 3].
The kernel of this theory is the equivalence principle of possible SP elements for different time moments [2]. As a result some special programs were created for optimum planning of the search of high orbital SOs. These programs were successfully tested in the 80s at a narrow-angle electro-optical sensor affiliated with SibirZMIR in Irkutsk (the site “Sayany”). Several years ago the perfected programs were implemented as the regular software at the electro-optical complex “Okno” in Tajikistan. The report on the results of their tests was presented at the 4th European Conference on Space Debris in Darmstadt in 2005 [4].

At the same time one needs to detect a SO given very imprecise a priori orbital information. That means that a state vector with large errors in all its components in the phase space (not only down track) is available. The examples of such situations are:
- a priori information available from a doubtful source,
- approximate orbital information available before the launch,
- orbital information on a SO lost very long ago,
- the SO state vector calculated by imprecise measurements,
- the SO state vector calculated by measurements over a small arc of its orbit,
- a very small field of view of the sensor.

In such a general case of a priori errors, application of TOPS and the equivalence principle is much more complicated. The more so, this principle loses its initial sense, which it had under the assumption of the state vector errors only along the track. The necessary generalization of the equivalence principle and further deepening the theory for the most general character of the state vector errors were suggested at the 5th European Conference on Space Debris in 2009 [5, 7].

In the light of TOPS observation of a SO by the assignment (using the one-valued ephemerides) can be considered as the particular (degenerated) case of the search situation, and can be struck off from the regular modes of the facility operation. Though at present, this is one of the main modes. So, such an approach to the monitoring of all space objects’ motion becomes more universal.

After thinking over this idea one can see that, namely, the search task rather than observation by assignment is the most natural sensor operation mode.

Firstly, the accuracy of a priori orbital information is continuously changing in time. And one cannot know beforehand that it will be enough, or not enough, when observation is needed.

Secondly, the same a priori orbital information for different sensors may lead both to observation of the SO by assignment (using precise targeting) and to the search task – depending on the mutual relation of the sizes of FoV and the SO CPUD.

The methods of optimum planning of the search allow to most economically use the sensor observation resource under the condition of a guarantee for the SO detection (if the intelligence signal power is sufficient for its acquisition).

With that the principal characteristics of the SSS would be enhanced (output capacity, detection reliability, the number of cataloged SOs, ) owing to the elimination of the errors of the 1st and 2nd kind, and the possibility of “wasteless” expansion of the SO CPUD. The SPs constructed in accordance with the TOPS have the property of the “wasteless” expansion of the sought for SO CPUD, in the sense that artificial expansion of CPUD (artificial deterioration of a priori state vector errors) does not involve any increase of waste of the search resource, because the SO will be detected in due course in accordance with the real size of its CPUD.

When one deals with a very faint intelligence signal (small size if a SO poorly reflecting surface material, wrong illumination phase, unhappy attitude or foreshortening), which does not allow detecting the SO using the traditional control of the sensors operation, the TOPS provides the observer with ample opportunity for raising the focal power of the sensor by transfer to the generalized ephemerides [8].

For enhancing the focal power by this approach one needs to compensate the signal motion on the receiver by the conformable motion of the sensor sight axis. But this is effective, only if the precise data on all orbital parameters are available. The peculiarity of our search task is that
there is very imprecise information on the sought for SO orbital parameters, including its velocities. So, the traditional approach to the problem does not give its solution.

At the same time the TOPS allows beneficially quantizing the whole great orbital data uncertainty into much smaller uncertainties in accordance with the number of the SP elements, and their location in the search space. As a consequence one can lessen the limiting observable size (or brightness) of SO.

With the aim of providing the more favorable conditions for concentrating and accumulating the faint intelligent signal energy at one point of the receiver, the sensor should realize a set of additional SP elements $\mu_{ij}$ during the exposition time period $(t_i^-, t_i^+)$, rather than only one fixed SP element $\mu_i$ of date $t_i$. By the way, this does not increase the whole time interval of the SP realization.

For the beginning of exposition $t^-_i$ the conditional ephemeris $(\alpha^-_i, \delta^-_i)$ is calculated by the center $< t^-_i, u^-_i >$ of the element $\mu^-_i$, which is a projection of $\mu_i$ along the equivalence curve [8] at the time $t^-_i$. Just since this moment, the receiver should be given a compensating motion conformable with the conditional rate of change of the argument of latitude which will bring it in time $\Delta t_{exp}$ to the position corresponding to $\mu^+_i$. The latter is a projection of $\mu_i$ along the equivalence curve at the time $t^+_i$ (the end of exposition). All this process is illustrated by Fig.1.

For comparatively small values of $\Delta t_{exp}$ it is enough to calculate the conditional coordinates of the SO $(\alpha^-_i, \delta^-_i)$ referred to the center of element $\mu^-_i$ and the rates of their change $(\alpha'^-_i, \delta'^-_i)$, which determine the compensation motion of the sight axis. For relatively great $\Delta t_{exp}$ the values of $\alpha'$ and $\delta'$ are to be corrected several times during the exposition. So, the preliminarily constructed SP element $\mu_i$ as it is being spread along the equivalence curve coming through its center, and the sensor realizes this "smear".

This technique can be applied both for searching and observing the small, or weakly-contrasting, SOs by precise appointments.

As an illustration, in Fig. 1 a fragment of the SP is shown. One can see the way how the usual SP is transformed to a set of the generalized ephemerides. One can also notice that the initially simple ephemeris is then being washed out down the equivalence curve into the generalized ephemeris which contains both angular coordinates $(\alpha, \delta)$ and their rates $(\alpha', \delta')$. Naturally, both the coordinates and rates here are conditional. That means that each set covers
only a part of the whole CPUD (a quantity of all uncertainty), its particular uncertainty being much less than that of the initial data (both in coordinates and in velocities).

In especially complicated cases (very imprecise a priori data) on the base of TOPS, one can substantiate and naturally realize the continuation of this approach, when passing the search task from one sensor to another, but with the reduced state vector errors.

**Conclusion.** So, the new theory of optimum planning of the search for a SO enhances the stability of space surveillance under the condition of the growth of the number of SOs owing to its merits: elimination of the errors of 1\textsuperscript{st} and 2\textsuperscript{nd} kind in the SP construction, “wasteless” expansion of the sought for SO CPUD, and the possibility to transfer to the generalized ephemerides which allows quantitizing the initial CPUD. These merits allow a struggle with the orbital data errors and, as a consequence, mitigate the stiff restrictions on periodicity of observations and release the observation resource. At last there is no need to consider the loss of a SO as a dramatic event, and it can be easily afforded.

**References**