SOME RESULTS OF TESTING THE NEW PROGRAM FOR SEARCHING SPACE OBJECTS IN DEEP SPACE

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ABSTRACT

At the 1st European Conference on Space Debris and at the 3d US/Russian Workshop on Space Surveillance, a new theoretical approach and the theory of searching deep-space objects by rough orbital information were suggested by one of the authors of this paper. This approach envisions a very special and mostly constructive operation and preparation of the space object current position uncertainty domain and its transformation. On the base of this theory some particular methods were developed and implemented at Optical-Electronical site "Okno" in Tajikistan. Some results of testing these programs during the real-time runs of the facility are presented. During this test about 20 deep space objects were found.

1. ABOUT THE PROBLEM

The actuality and topicality of the problem of searching for deep-space objects proceeds even if from the fact that the real amount of space objects in highly-elliptical orbits is about 20-30 times more than there are contained in the joint US/Russian space objects catalog (anon., 1995; anon., 1989).

The main feature of the problem is that we usually have only rough a priori orbital information on the sought for space object (SO). On such conditions, the traditional approach of sounding space, or sequentially scanning the area of space with the aim of acquisition of a weak intelligence signal appears to be ineffective.

This is due to a very large deep-space object current position uncertainty domain to be covered by the search moves and its complex transformation in time, due to too much energy consumption because of a great distance to the SO, the indispensable requirement of appropriately accurate compensation of the SO motion for concentrating the signal energy at the same spot of the receiver, and to lack of optimum search procedures.

2. REVIEW OF THEORY

In (Veniaminov S. 1993, Veniaminov S. 1998a, Veniaminov, S. 1998b, Veniaminov, S. 1998c) the theory of optimum planning the search of deep-space objects in the absence of precise orbital information was developed. There was received the set theory statement of the problem on the basis of the search plans equivalence principle (Вениаминов С. 1984, Вениаминов С. 1983).

First of all, the theory is aimed at the most efficient and accurate use of available rough a priori orbital information on a sought for SO, and of its current position uncertainty domain dynamics (its drift and deformation) while simultaneously taking into account the concrete properties and technical characteristics of the sensor used.

As it was suggested in (Veniaminov, S. 1998a), the search problem constructively comes to choosing a sequence of conditional ephemeredes and the related conditional velocities of the SO's supposed motion, which are optimum with respect to the adopted efficiency criterion under the restrictions laid by technical capabilities and properties of the sensor.

This set of conditional ephemeredes and velocities (so called the generalized ephemeredes (Veniaminov, S. 1998c)) should completely cover not only the area of space, but the continuously drifting and topologically deforming SO's current position uncertainty domain. At the same time, it should be the most economic one. Eventually, after its realization, all the complex of necessary favorable conditions for right targeting the sensor, for concentrating and accumulating the wanted intelligence signal energy in one point of the receiver must be provided in one and only one case, that is for only one conditional ephemeris out of the set. But that will do for solving our problem.

All these requirements were taken into account while constructing the theory. Drawing upon this theory, several methods for searching deep-space objects were constructed and implemented at some sensors, one of them ("Okno") being located in Tajikistan. The methods realize the discrete search optimum plans by the argument of latitude ***u*** as they are defined in (Veniaminov S. 1998c). One of them is a search method starting from the edge of search interval (Fig.1), the (second one is a search method starting from the center of search interval (Fig.2).

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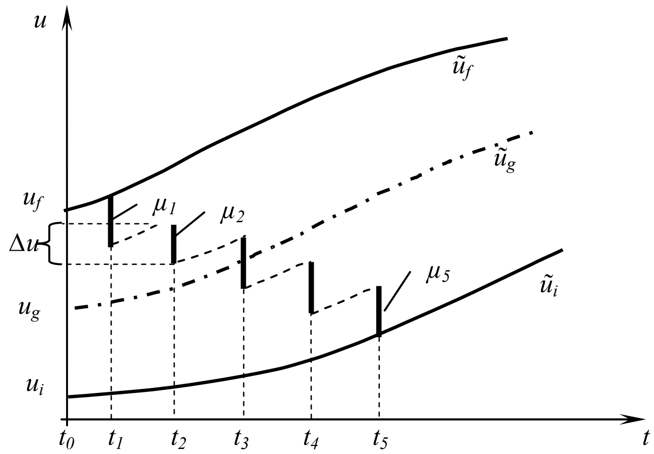

Figure 1. Search starting from the edge of search interval

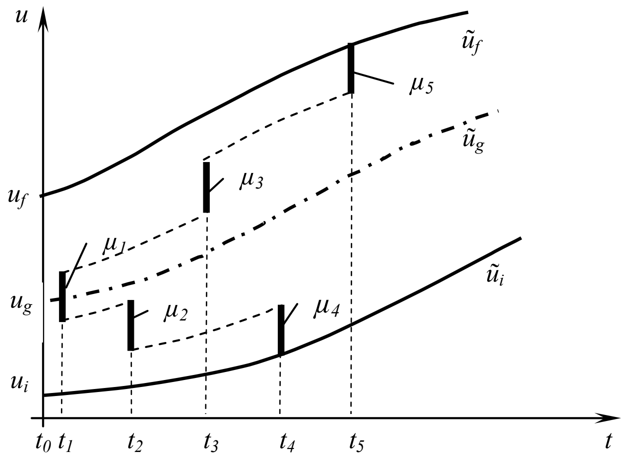

Figure 2. Search starting from the center of search interval

Here:
u_i – the beginning of search interval (*u* initial*)* at time t_0;
u_f - the end of search interval (*u* final) at time t_0;
u_g – the argument of latitude out of the given vector of SO orbital parameters;
μ_i – the search plan element (*i*-th conditional ephemeris) planned for realization at time t_i;
$\tilde{u}_i = \tilde{u}_i(t)$ – the equivalence curve crossing the argument of latitude u_i at time t_0;
$\tilde{u}_f = \tilde{u}_f(t)$ – the equivalence curve crossing the argument of latitude u_f at time t_0;
$\tilde{u}_g = \tilde{u}_g(t)$ – the equivalence curve crossing the argument of latitude u_g at time t_0.

3. TEST RESULTS

Both proposed methods and the traditional one (for comparison) were tested for determination of their detection reliability and drive efficiency (speed). The last property was estimated by the time input Δt_s since the beginning of search t_1 through the time of real acquisition of sought for space object signal t_{acq}:

$$\Delta t_s = t_{acq} - t_1$$

The reliability of acquisition was estimated as the ratio of the number of successfully detected SOs to the whole number of SOs taken for the test on the condition that the sensor technical characteristics and the astro-ballistic conditions provide the sensor with the opportunity of detecting SO and these are equal for all methods involved.

For the test, 22 deep space objects in highly elliptical and 12-hour circular orbits were chosen, 10 of them were used for comparative estimation of two proposed methods and the traditional one, 12 other space objects were used for comparison of the proposed methods between themselves. In first case the field of view was 30 angular minutes, in second one - 10′.

The search was conducted first by the traditional method of sequentially scanning the static search area (in the sensor picture plane), then by the new methods. All the results of the test are placed in Tables 1 and 2.

The test showed essential superiority of both new methods against traditional one. The last one failed to detect SOs №№ 94051001, 02017001, 98054001, 01004001, meanwhile both new methods detected all space objects involved in the test. This fact can be accounted for by that the traditional method does not take into account the proper complex real dynamics of SO current position uncertainty domain during the search process.

In fact, it was stated that the new methods decreased the detection process duration at average by 73 % (that is 3.8 times) and increased the acquisition reliability by 40 %.
When the new methods were compared with each other, the second method (starting from the center of search interval) appeared faster by 47.2 %. The detection reliability appeared to be the same for both methods, that is 100 %.
Regular application of both methods for about a year at the “Okno” site confirmed their very high efficiency.

Table 1. Results of testing the traditional and proposed search methods

International №	Orbit	Search method	Dimension of search area (degree)	Date (dmy)	t_s (h:m:s)	t_{acq} (h:m:s)	Δt_{search} (h:m:s)
01053002	CO	1	2X0.5	130204	20:35:40	20:36:17	0:00:37
		2	2X0.5	130204	20:40:54	20:41:10	0:00:16
		3	2X2	130204	20:43:42	20:44:11	0:00:29
01050001	HEO	1	2X0.5	120204	0:33:11	0:33:57	0:00:46
		2	2X0.5	120204	1:33:00	1:33:16	0:00:16
		3	2X2	120204	1:35:27	1:37:15	0:01:48
01050001	HEO	1	2X0.5	140204	1:42:02	1:42:20	0:00:18
		2	2X0.5	140204	2:21:14	2:21:33	0:00:19
		3	2X2	140204	2:23:40	2:24:52	0:01:12
94051001	HEO	1	2X0.5	130204	19:53:49	19:54:31	0:00:42
		2	2X0.5	130204	19:59:52	20:00:14	0:00:22
		3	2X2	130204	20:02:12	-	-
01004001	CO	1	3,6X0.5	130204	20:08:13	20:09:18	0:01:05
		2	3,6X0.5	130204	20:12:32	20:12:51	0:00:19
		3	3X3	130204	20:17:11	-	-
02017001	HEO	1	2X0.5	130204	20:47:07	20:47:36	0:00:29
		2	2X0.5	130204	21:05:18	21:05:36	0:00:18
		3	2X2	130204	21:09:08	-	-
74026001	HEO	1	2X0.5	130204	21:14:31	21:15:11	0:00:40
		3	2X0.5	130204	21:19:14	21:19:30	0:00:16
		4	2X2	130204	21:21:32	21:22:02	0:00:30
98054001	HEO	1	2X0.5	140204	1:17:21	1:18:06	0:00:45
		2	2X0.5	140204	1:22:41	1:22:57	0:00:16
		3	2X2	140204	1:39:30	-	-
97015004	HEO	1	2X0.5	140204	1:27:45	1:28:27	0:00:42
		2	2X05	140204	1:34:04	1:34:22	0:00:18
		3	2X2	140204	1:36:49	1:37:20	0:00:31
86065001	HEO	1	2,2X0.5	110204	2:02:40	2:03:24	0:00:44
		2	2,2X0.5	120204	1:59:06	1:59:21	0:00:15
		3	2X2	120204	2:05:17	2:07:59	0:02:42

Table 2. Results of comparatively testing two proposed search methods

International №	Orbit	Search method	Dimension of search area (degree)	Date (dmy)	t_s (h:m:s)	t_{acq} (h:m:s)	Δt_{search} (h:m:s)
01050001	HEO	1	1.6 X 0.5	150204	19:39:32	19:40:38	0:01:06
		2	1.6 X 0.5	150204	19:44:51	19:45:33	0:00:42
82015001	HEO	1	1.8 X 0.5	150204	19:50:14	19:51:31	0:01:17
		2	1.8 X 0.5	150204	20:03:59	20:04:40	0:00:41
80063004	HEO	1	1.2 X 0.5	150204	19:56:01	19:57:00	0:00:59
		2	1.2 X 0.5	150204	19:59:36	19:59:52	0:00:16
98054001	HEO	1	2.6 X 0.5	150204	20:06:36	20:07:58	0:01:22
		2	2.6 X 0.5	150204	20:12:13	20:12:29	0:00:16
94051001	HEO	1	2.2 X 0.5	150204	20:18:23	20:19:39	0:01:16
		2	2.2 X 0.5	150204	20:24:50	20:25:05	0:00:15
01004001	CO	1	2.6 X 0.5	150204	20:27:33	20:29:00	0:01:27
		2	2.6 X 0.5	150204	20:33:09	20:33:40	0:00:31
02017001	HEO	1	2.6 X 0.5	150204	20:30:07	20:31:38	0:01:31
		2	2.6 X 0.5	150204	20:33:09	20:33:40	0:00:31
74026001	HEO	1	3 X 0.5	150204	20:53:01	20:54:49	0:01:48
		2	3 X 0.5	150204	20:56:07	20:57:00	0:00:53
85088001	HEO	1	3.8 X 0.5	150204	21:06:52	21:08:56	0:02:04
		3	3.8 X 0.5	150204	21:10:39	21:11:30	0:00:51
86065001	HEO	1	1.8 X 0.5	150204	21:32:09	21:33:22	0:01:13
		2	1.8 X 0.5	150204	21:37:25	21:38:54	0:01:29
97015004	HEO	1	2.8 X 0.5	150204	21:21:23	21:23:07	0:01:44
		2	2.8 X 0.5	150204	21:26:59	21:27:41	0:00:42
77010001	HEO	1	1.3 X 0.5	150204	21:56:04	21:57:04	0:01:00
		2	1.3 X 0.5	150204	22:00:37	22:01:23	0:00:46

Here:
1 – search method starting from the edge of search interval;
2 - search method starting from the center of search interval;
3 – traditional search method of sequentially scanning the search area;
CO – 12-hour circular orbit;
HEO – highly elliptical orbit.

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