ORBITS AND POINTING STRATEGIES FOR SPACE BASED TELESCOPES INTO AN EUROPEAN SPACE SURVEILLANCE SYSTEM

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ABSTRACT

This paper describes the inclusion of optical images acquired from orbiting telescopes into an autonomous European space surveillance system via the Advance Space Surveillance System Simulator (AS4). Special interest on space-based observation of GEO objects exists since it avoids the weather dependence and longitudinal restrictions of ground-based observations of those objects. Furthermore, space-based observations allow the detection of small objects that are not detected from ground-based sensors.

In order to analyze the impact of space-based telescopes images, several aspects have to be studied. The first consideration is the selection of the appropriate orbits to locate the telescopes. A description of the most suitable orbits and strategies for the observation of space debris population will be provided.

Once an appropriated orbit has been selected, the next important consideration is the analysis of an optimized pointing strategy and its associated requirements for feasibility. Several pointing strategies will be exposed by analyzing, among other factors, the impact of luminosity conditions in the most populated regions to be observed. Numerical results are presented in the form of statistics, which reflect the compromise between the density of detected objects, and other important parameters for orbit determination and cataloguing purposes as re-acquisition times or measurement track duration.

Finally, overall analyses of possible space-based constellations are presented. Such constellations are aimed to solve the main drawbacks in considering only one satellite at the selected orbit. This is for example the case of revisit times when considering a sub GEO orbiting telescope which can be solve by re-distributing several sensors in the orbit. It will also allow carrying on more complex pointing strategies by the definition of several sensors located at same orbit pointed at two different regions.

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1. INTRODUCTION

This work is the continuation of a previous work of the authors (see [4]). It is focussed on the GEO observation capabilities from Space Based (SB) telescope platform. However, preliminary analysis of the capabilities for the rest of type of orbit is also included. The work is structured in the following way. Section 2 describes the selected orbits for locating the telescope as well as the telescope pointing. In section 3 the orbital determination and cataloguing capabilities for the proposed SB telescope strategies are studied and analysed in terms of sensitivity, coverage, timeliness, etc. Section 4 analyses the feasibility of the proposed strategies in terms of the pointing law. Section 5 speaks about some proposed space based constellations aimed to solve the main drawbacks in considering only one satellite at the selected orbit. Finally, section 6 concludes this work with a discussion on the most adequate SB telescope strategy.

1.1. Simulated Space Debris Population

The population that will be considered for the numerical simulations has been provided by ESA (European Space Agency). Table 1 shows the definition of each type of orbit as well as the number of objects in the population with size greater than 5 cm (full population includes objects larger than 1cm).

Table 1:Population characteristics for the numerical simulations

Orbit Type	CONDITION	Objects (>5 cm)
LEO	Apogee < 2000 km	21,484
MEO	1.5 < Mean Motion < 2.5 rev./day Inclination < 67°	1,392
GEO	Perigee > 34000 km Apogee < 38000 km	7,964

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GTO	Perigee < 2000 km 30000 < Apogee < 45000km	218
Other	Other wise	12,779
ALL	----	43,837

2. DESCRIPTION OF OBSERVATION STRATEGIES

In this section we follow the same ideas as [4] in order to propose (and analyse) several SB telescope strategies. In this work we include two additional strategies with the telescope in GTO orbit. Read [4] in order to have a more detailed explanation on the strategies.

2.1. Simulated Observation Strategies

Depending on the orbit where the telescope is located and the selected strategy, different observation capacities are obtained. The simulated cases presented in this paper are summarised in the following:

- **LEOEQ:** One Space Based telescope located at a LEO equatorial orbit with along-track pointing.
- **LEOSS2P:** One Space Based telescope located at LEO Dawn Dusk orbit with pointing at GEO ring (two points, 20º apart Sun-Earth line, avoiding Earth shadow).
- **LEOSSPINCH:** One Space Based telescope located at LEO Dawn Dusk orbit pointing at appropriate Pinch Point in GEO ring (date selected for the optimisation of illumination condition: one point 20º apart Sun-Earth line).
- **SUBGEO:** One Space Based telescope located at a Sub-GEO orbit (40000 km) with along-track pointing.
- **GTOSUNP:** One Space Based telescope located at GTO orbit with its perigee in the Sun direction pointing at two points, 20º apart Sun-Earth line, avoiding Earth shadow.
- **GTOSUNV:** One Space Based telescope located at GTO orbit with its perigee in the Sun direction with along-track pointing.

3. ORBIT DETERMINATION AND CATALOGUING CAPABILITIES FOR THE SIMULATED STRATEGIES

The characteristics of the set of measurements provided by Space Surveillance System provide good indicators of the goodness of the system to create and maintain a future Catalogue of Space Debris. The purpose of this section is to analyze which are the best performances that may provide one Space Based Telescope only. There are three different aspects that must take into account in order to create and maintain a catalogue:

- **Size of the Catalogue:** A good indicator is the minimum size of observable objects: The smaller the **minimum size** of observable objects; the larger the number of objects contained the catalogue and better control over the full set of space debris. Of course the number of **observed and observable objects** is also a good indicator of the size of the catalogue.
- **Maintenance of the catalogue:** Good indicators of the goodness of the system to maintain a catalogue are the **period of re-observation** of the already catalogued objects and the number of images inside a track: On one hand the shorter the maximum re-observation period; the more often the object is observed and better the accuracy of the estimated state vector. On the other hand, the more images inside the track; more information we have about the position of the object and better will be the accuracy of the estimated state vector.
- **Creation of a catalogue:** The **duration of the track** and the number of images inside the track are good indicators of the goodness of the system to create a catalogue of Space Debris from scratch: The longer the duration of the track, more information we have associated to one object and better accuracy we can achieve from the Initial Orbit Determination activities. On the other hand, **the time of first appearing of a new object** provides an indicator of the time required to create a catalogue. The shorter the first time of object appearing, the sooner we observe the objects, and the sooner the catalogue will be created.

We have analyzed a total of 6 different telescope strategies. We have generated the corresponding set of measurements and we have generated histograms, distribution functions and statistics of all these indicators. This study has been performed by different type of orbits independently. We will focus our discussion on the results obtained for GEO type objects. However, we will comment also the performances for the rest of orbit types.

For LEO type of orbits, 7 days has been simulated. For the rest of type of orbits the numerical simulations have been performed during 30 days. It has been considered telescopes with 15º of FOV and 0.15m of aperture.

3.1. Number of observable and observed GEO objects

In this section we will answer the question: which strategy observe more objects? And which strategy may observe more objects. Table 2 shows the number of observable and observed objects for each SB telescope strategy and for each type of orbit. Observable objects are those objects that could be observed by the sensor with enough time; they have appropriate characteristics to be observed: size, proper orbit with respect the sensor, etc.. On the other hand, observed objects are those objects that have been detected during the simulated days. In general, the duration of the numerical simulation is not adequate for the simulated strategy when an observable objects is not observed.

Table 2- Observable and Observed objects

	Strategy	Observable Objects	Observed Objects
7964 simulated GEO objects	**LEOEQ**	893	892
	LEOSS2P	881	853
	LEOSSPINCH	881	688
	SUBGEO	3104	986
	GTOSUNP	2365	941
	GTOSUNV	2054	952
21484 simulated LEO objects	**LEOEQ**	15617	4240
	LEOSS2P	18186	7417
	LEOSSPINCH	18232	5970
	SUBGEO	0	0
	GTOSUNP	10752	863
	GTOSUNV	8264	717
1392 simulated MEO objects	**LEOEQ**	957	701
	LEOSS2P	893	572
	LEOSSPINCH	894	393
	SUBGEO	602	75
	GTOSUNP	920	490
	GTOSUNV	910	328
218 simulated GTO objects	**LEOEQ**	131	60
	LEOSS2P	123	60
	LEOSSPINCH	133	42
	SUBGEO	3	3
	GTOSUNP	104	47
	GTOSUNV	131	60
12779 OTH objects	**LEOEQ**	3168	1076
	LEOSS2P	3076	1373
	LEOSSPINCH	3098	1103
	SUBGEO	3339	210
	GTOSUNP	4430	740
	GTOSUNV	3125	504

Numerical results for GEO objects: There are two set of results clearly identified. On one hand, results corresponding to SB telescopes in LEO orbit: almost 900 objects are observable objects. LEOEQ strategy provides the best numerical results with 893 observable objects and 892 observed objects. Strategy LEOSS2P provide also good results with 881 observable objects and 853 observed objects.

On the other hand the numerical results corresponding to SB telescopes located in GTO and SUBGEO orbits. The number of observable objects increase more than twice (for GTO orbit) or three times the number of observable (for SUBGEO orbit) the number of observable from SSO. The reason is very clear. The telescope is closer than the telescope in LEO orbit to the observed region. Therefore it can detect smaller objects. The SB telescope in SUBGEO platform provides the best results in terms of observable (3104) and observed objects (986). The numerical results in terms of observed objects for GTOSUNV are also very similar to the ones obtained with SUBGEO (952 vs. 986).

Numerical results for the rest of orbit types: For the rest of type of orbit, observing from LEO orbit provides better results than observing from GTO or SUBGEO orbit. In these cases LEOEQ and LEOSS2P are the strategies with better performances. For LEO and OTH objects, the better observation strategy in terms of number of observed objects is LEOSS2P. For MEO objects, LEOEQ provides better results than LEOSS2P strategy. Similar performances are obtained with LEOEQ and LEOSS2P for GTO objects.

3.2. Period of re-observation

The re-observation period is a good indicator of the goodness of the set of measurements to maintain a catalogue: the lower the re-observation period, the more often the objects are observed, and better the orbital determination and therefore better conditions for maintaining a catalogue. Table 3 shows the mean of the re-observation period and the maximum re-observation period for the observed objects. The difference between these two values is: in the first case, we consider the full set of measurements; we compute the corresponding re-observation period for the full set of measurements; and then, the mean of this set. In the second case; we compute for each observed object, which has been the maximum re-observation period, and then, we compute the mean of these maximum values.

Table 3- Mean and Maximum period of re-observation

	Strategy	Mean re-observation period (hours)	Maximum re-observation period (hours)
7964 simulated GEO objects	**LEOEQ**	3.672	16.299
	LEOSS2P	12.600	32.468
	LEOSSPINCH	19.007	33.887
	SUBGEO	216.623	300.071
	GTOSUNP	27.437	80.863
	GTOSUNV	36.438	123.412
21484 simulated LEO	**LEOEQ**	31.042	68.045
	LEOSS2P	20.439	69.987
	LEOSSPINCH	18.719	68.268
	SUBGEO	-	-
	GTOSUNP	63.142	82.530
	GTOSUNV	86.428	83.116
1392 simulated MEO objects	**LEOEQ**	11.273	123.408
	LEOSS2P	30.557	211.251
	LEOSSPINCH	37.673	250.356
	SUBGEO	104.802	231.534
	GTOSUNP	84.722	328.258
	GTOSUNV	35.968	130.528
218 simulated	**LEOEQ**	6.942	123.567
	LEOSS2P	39.808	228.684
	LEOSSPINCH	36.486	265.347
	SUBGEO	216.092	286.778
	GTOSUNP	95.353	266.909

	GTOSUNV	28.752	79.208
12779 OTH objects	**LEOEQ**	16.521	173.410
	LEOSS2P	32.050	210.762
	LEOSSPINCH	34.180	225.559
	SUBGEO	218.771	399.700
	GTOSUNP	93.965	274.881
	GTOSUNV	61.291	117.420

Numerical results for GEO objects:

One GEO object is considered correctly maintained when it is observed at least once each 48 hours. That means, when its maximum re-observation period is lower than 48 hours. With this definition, only LEOEQ, LEOSS2P and LEOPINCH provide adequate performances (in decreasing order of performances). If we relax this condition and we define as correctly maintained those objects that in general are observed each 48 hours, strategies with the telescope in GTO orbit would also provide proper results.

Numerical results for the rest of orbit types:

One LEO object is considered correctly maintained when it is observed at least once each 24 hours. None of the simulated strategy provides adequate performances. However, if the definition is relaxed and we consider the mean of the re-observation periods and not the maximum, strategies with the telescope in SSO (LEOSS2P and LEOPINCH) would satisfy the constraint. One MEO object is considered correctly maintained when it is observed at least once a week. There are not yet a common definition of the required re-observation time for of correctly maintaining GTO and OTH objects. Here we will consider the same constraints as for MEO objects. In this case strategies LEOEQ and GTOSUNV satisfy the constraint (LEOEQ for OTH orbits does not satisfy the definition but it is very close).

3.3. Sensitivity and Timeliness

The sensitivity of the strategy is the minimum size that can be observed. The numerical results are shown in the second column of Table 4.

Sensitivity for GEO objects:

The results are clearly grouped in two different sets: those strategies that observe objects greater than 1 meter (corresponding with the strategies with the SB telescope located in LEO orbit); and the strategies that the SB telescope passes close to the GEO ring and therefore they observe smaller objects (20cm or 7 cm) that correspond with the strategies with the telescope located in GTO or sub-GEO orbit. From the first set of strategies the better performances are obtained with LEOEQ. Up to 1.54 meters are observed in GEO ring. After LEOEQ, LEOSS2P observes objects up to 1.88-meter size. From the second set of strategies, telescopes located in GTO orbit observe smaller objects than telescopes located in sub-GEO orbit. Of course, this result depends on the sub-GEO orbit where the telescope is located. We can consider a sub-GEO orbit closer to GEO ring. In this case, we can obtain better results than with telescopes in GTO orbit. However, the re-observation period will increase a lot.

Sensitivity for the rest of type of orbit:

Numerical results for LEO objects show the contrary situation than for GEO objects. In this case, telescopes located in LEO orbit are closer to LEO objects than telescopes located in GTO and sub-GEO (where no LEO objects is observed) orbits. Therefore, smaller objects are observed from LEO orbit. Similar results are obtained for MEO objects with strategies with telescope located in LEO orbit and with the telescope located in GTO orbit. In case of GTO objects, better results are obtained with strategies LEOEQ, LEOSS2P and LEOSSPICH. In case of OTH objects observation; all strategies with exception of GTOSUNV provide similar performances.

Table 4- Minimum detected size and Survey Timeliness

	Strategy	Minimum Detected size (m)	Survey Timeliness
7964 simulated GEO objects	**LEOEQ**	1.54	7.598
	LEOSS2P	1.88	18.556
	LEOSSPINCH	1.98	20.985
	SUBGEO	0.22	204.236
	GTOSUNP	0.07	45.844
	GTOSUNV	0.11	92.280
21484 simulated LEO	**LEOEQ**	0.05	47.870
	LEOSS2P	0.05	53.081
	LEOSSPINCH	0.05	51.666
	SUBGEO	-	-
	GTOSUNP	0.10	71.306
	GTOSUNV	0.12	270.346
1392 simulated MEO objects	**LEOEQ**	0.09	79.965
	LEOSS2P	0.08	153.405
	LEOSSPINCH	0.08	184.153
	SUBGEO	0.10	108.634
	GTOSUNP	0.06	264.670
	GTOSUNV	0.08	224.722
218 simulated GTO objects	**LEOEQ**	0.05	6.942
	LEOSS2P	0.07	39.808
	LEOSSPINCH	0.07	36.486
	SUBGEO	1.91	216.092
	GTOSUNP	0.16	95.353
	GTOSUNV	0.47	28.752
12779 OTH objects	**LEOEQ**	0.06	126.896
	LEOSS2P	0.05	158.730
	LEOSSPINCH	0.05	178.364
	SUBGEO	0.06	353.131
	GTOSUNP	0.05	226.640
	GTOSUNV	0.11	217.342

The timeliness is the time that the sensor takes to detect a new object. In this case, the lower the timeliness, the sooner the object is detected and therefore the sooner the catalogue can be created.

<u>Timeliness for GEO objects:</u> LEOEQ strategy provides the shorter timeliness for GEO objects. Only 7.5 hours (in mean) requires the sensor for detecting new objects. LEOSS2P and LEOSSPINCH also provide good results. Less than one day is required for a new object being detected with these two strategies.

<u>Timeliness for the rest of type of orbit:</u>

The numerical results for LEO objects are not appropriate at all. Any of the simulated strategies provide reasonable results for LEO type of orbit. The lower timelines is obtained with LEOEQ, almost two days are required for detecting a new LEO objects. The typical timeliness obtained from radar is lower than 10 hours.

For the rest of type of orbits, since we have assumed as correctly maintained those objects that are observed at least once a week, we will consider reasonable timeliness all these values lower than 168 hours. For MEO orbits the better results are obtained with LEOEQ strategy, only 79 hours are required for detecting a new object. For GTO objects better results are obtained with LEOEQ strategy, but also with LEOSS2P and LEOSSPICH and GTOSUNV. For OTH type of orbits the better results are provided by LEOEQ and LEOSS2P.

3.4. Duration of tracks and number of tracks per object

When a new object is detected, an initial orbit determination must be computed. In order to compute an initial orbit determination a minimum of three pairs of azimuth and elevation inside the track is required. When the track has less than three pairs of measurements the initial orbit determination cannot be computed. Moreover, the greater the number of measurements inside the track; the better the accuracy in the IOD computation. On the other hand, the duration of the track plays also a relevant role in the IOD computation. The longer the duration of the track; the more accurate the IOD computation is. Table 5 shows the mean track duration and the mean number of tracks per object. The proper duration of tracks for computing accurate initial estimations of the debris state vectors depends strongly on the numerical tools, and algorithms used for the Initial Orbit Determination. AS4 simulator uses algorithms similar to those described in [3]. Let us comment the results in terms of duration of tracks:

It is difficult to analyze the goodness of the duration track independently. It is clear that the longer the track duration, more orbital information we have and better the IOD. But, the most important issue is how long is the validity period of that IOD. Or in other words, does the accuracy achieved with the IOD allow determining the orbit with the re-observation period of the corresponding strategy? Therefore, the duration of the track must be analyzed together with the re-observation period. For instance, for GEO objects in case of LEOEQ strategy, the duration of the track is lower than 5 minutes. That would imply poor accuracy for IOD. However, the re-observation period in this case (in mean) is only about 3,5 hours. Does the IOD degrade so much than in 3 hours the object will become un-correlatable? On the other extreme, the duration of the track for GEO objects in case of SUBGEO strategy is longer than 4 hours, but the re-observation period is, in mean, longer than 9 days. May be the IOD valid during 9 days? A more accurate analysis must be done by computing the IOD and the corresponding validity period for all these strategies. This analysis would allow concluding which are the adequate or inadequate strategies in terms of track duration.

The mean number of tracks per object is an indicator of the redundancy of data for the orbit computation. We want to remark that the simulated duration for LEO objects is 7 days, for the rest of objects 30 days have been considered. Therefore one or two tracks per GEO object (as in case of SUBGEO) corresponds to very poor results.

Table 5- Duration of tracks and Number of tracks per object.

	Strategy	Duration of track (seconds)	Number of tracks per object
7964 simulated GEO objects	**LEOEQ**	206.167	191.404
	LEOSS2P	1501.934	51.352
	LEOSSPINCH	1732.161	33.504
	SUBGEO	15758.999	2.370
	GTOSUNP	3129.179	22.823
	GTOSUNV	1938.211	15.373
21484 simulated LEO objects	**LEOEQ**	29.746	3.867
	LEOSS2P	31.515	5.756
	LEOSSPINCH	37.289	6.310
	SUBGEO	-	-
	GTOSUNP	59.844	1.563
	GTOSUNV	43.638	1.890
1392 simulated MEO objects	**LEOEQ**	181.826	58.234
	LEOSS2P	916.872	19.098
	LEOSSPINCH	1001.172	14.987
	SUBGEO	2539.586	4.200
	GTOSUNP	1777.590	5.945
	GTOSUNV	954.668	9.829
218 simulated GTO objects	**LEOEQ**	157.212	93.883
	LEOSS2P	698.250	15.350
	LEOSSPINCH	910.075	31.336
	SUBGEO	2096.250	3.000
	GTOSUNP	879.088	5.830
	GTOSUNV	903.565	17.848
12779 OTH objects	**LEOEQ**	169.461	35.881
	LEOSS2P	376.269	16.784
	LEOSSPINCH	334.980	15.172
	SUBGEO	2991.773	2.310
	GTOSUNP	1153.423	39.447
	GTOSUNV	977.427	5.335

4. FEASIBILITY OF PROPOSED STRATEGIES

In this section we want to analyse the feasibility of the previously defined and studied strategies in terms of the feasibility of the telescope pointing evolution. In order to show the telescope pointing evolution a coordinate system has been defined on the telescope. The X-axis follows the velocity direction; the Y-axis is the perpendicular direction out the orbit plane; and Z-axis completes the reference system. The telescope pointing evolution is characterized by the functions that describe azimuth and elevation angles in this reference system. The elevation angle is defined by the pointing of the telescope outside the XY plane. The azimuth is the angle of the projection of the pointing in the XY plane with respect the X-axis.

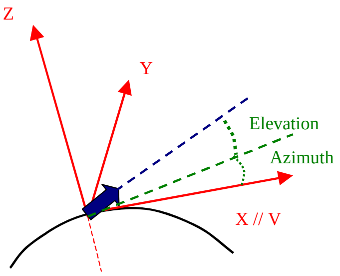
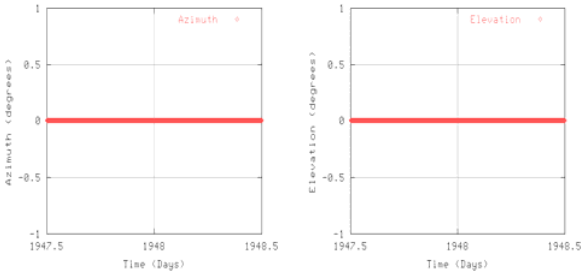


Figure 1: Reference system where the telescope pointing evolution is defined.

The derivative of azimuth and elevation behaviour is also very important because they will determine the viability of the pointing strategies as function of the maximum velocity of the telescope motion. Telescope strategies with discontinuities in angular values or high values in the angular derivatives may cause problems in the telescope pointing control.

We have numerically analysed the telescope evolution pointing corresponding to the simulated strategies of this work. On one hand, the strategies with along-track direction pointing (LEOEQ, SUBGEO and GTOSUNV) have a very simply pointing evolution (as one could expect) without any discontinuity. The pointing telescope is defined fixed in the local frame. Therefore the azimuth and elevation evolution are always constant and the corresponding derivatives null (see Figure 2).



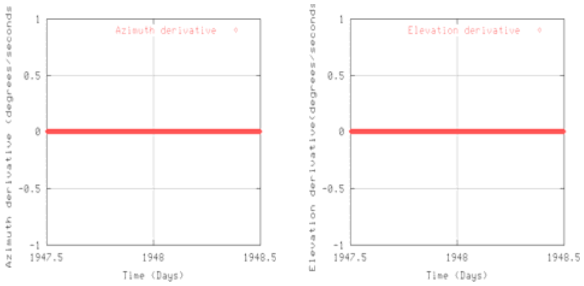


Figure 2: Along track pointing evolution (corresponding to LEOEQ, SUBGEO and GTOSUNV).

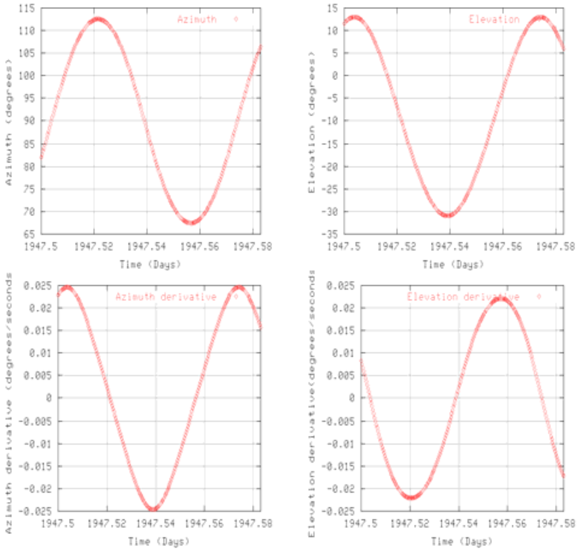
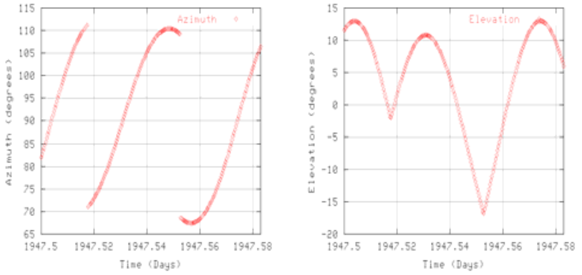


Figure 3: Azimuth and Elevation evolution when the pointing is fixed to an inertial point (fixed with respect the sun direction). Sun-synchronous orbit is considered here. (Pointing corresponding to LEOSSPINCH).

In case of the LEOSSPICH, the evolution of the azimuth and elevation angles is not so simple as it was in the previous case. Although the evolution is not constant, the behaviour is quite regular. It follows sinusoidal functions with the same period as the telescope orbital period (see Figure 3). The derivatives of these angles have maximum of 0.02 degrees/second (approximately). Therefore, they seem to be feasible even for simple control systems.



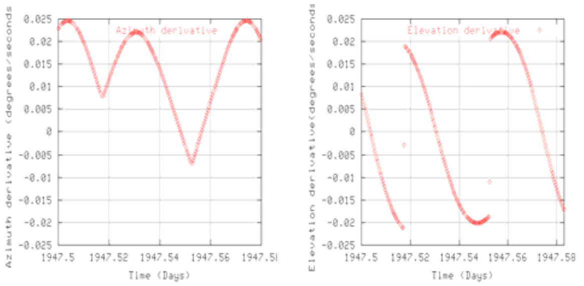


Figure 4: Azimuth and Elevation evolution when the pointing changes to two different inertial points (two points are fixed with respect the sun direction). Sun-synchronous orbit is considered here. (Pointing corresponding to LEOSS2P).

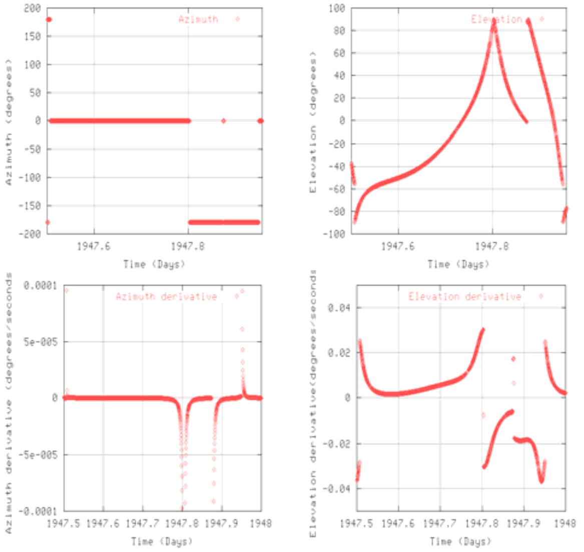


Figure 5: Azimuth and Elevation evolution when the pointing fixed to one inertial point (with respect the sun direction) in GTO orbit. (Pointing corresponding to GTOSUNP).

In case of the pointing corresponding with LEOSS2P strategy, there are two points in the telescope orbit where the pointing is suddenly changed. They produce discontinuities in the azimuth and elevation evolution as well as the corresponding two points where the derivatives are not defined. The range of elevation that is covered with this strategy is approximately 30 degrees versus the 45 degrees recovered by LEOSSPINCH. The time required for stabilizing the telescope in these two points of discontinuity must be analysed in order to determine the current feasibility of this strategy (see Figure 4).

In case of the GTOSUNP telescope strategy has four points of discontinuity in the evolution of azimuth and elevation and where the derivatives are not defined (see Figure 5). The discontinuities are related with the pericentre and the apocentre of the telescope orbit. Discontinuities close to pericentre are not relevant because the Earth limb is in the FOV of the telescope and measurements are not taken anyhow. However discontinuities close to apocentre present a considerable inconvenient for GEO observations. Close to the apocentre is when the telescope is closest to GEO ring and therefore is when smaller objects may be detected. The time required for stabilizing the telescope should be analysed.

5. SPACE BASED CONSTELLATIONS

Different constellations are proposed in order to solve some problems mentioned before for the single-telescope strategies:

Constellations for small GEO objects observation:

Those strategies with the telescope closer to GEO ring provide optimal results in terms of sensitivity. But the coverage performances become very poor. In order to solve this drawback, that is in order to decrease the (maximum) re-observation period up to 48 h, the solution is considering a constellation of telescopes located at the same orbit, but equally spaced in the orbit. For instance, for the simulated SUBGEO strategy, with only one telescope the maximum re-observation period is of 300 hours. That means that 6 or seven telescopes are required for obtaining proper coverage performances (300/6=50 hours; 300/7=43 hours). In general, as closer the telescope in SUBGEO orbit is, smaller GEO objects will be detected, but higher the re-observation period will be, and therefore more telescopes in the constellation will be required. In case of locating the telescope in GTO orbit, the performances in terms of sensitivity are also good, and the re-observation period is not so high as in SUBGEO case. Only two or three telescopes will be required for obtained adequate re-observation periods.

Constellation for avoiding pointing laws difficulties:

The telescope strategy when the pointing changes to two different inertial points has the inconvenience that the pointing law has two (or 4 for GTO orbit) discontinuities in the azimuth and elevation evolution. That means that the telescope requires some time to stabilise the pointing after the sudden change. When this time becomes dramatic a constellation of telescope may be considered. For example, two telescopes located at LEO SSO orbit, one pointing at 20º with respect to the Earth-Sun line and the other pointing at –20º may substitute LEOSS2P strategy. Since the observation points are continuously pointed, no large changes in the azimuth laws are imposed and the pointing laws would be similar to the LEOSSPINCH case.

6. SUMMARY AND CONCLUSSIONS

In this work we have analysed six space-based strategies in terms of number of observable and observed objects, mean and maximum re-observation period, sensitivity, timeliness, duration of tracks and number of images inside tracks. Numerical results for GEO, but also for LEO, MEO, GTO and OTH type of orbit have been provided. The feasibility of the telescope pointing laws has been studied in terms of azimuth and elevation evolution and corresponding derivatives behaviour. Finally, some architectures are proposed for solving concrete problems of some particular telescopes strategies.

This work may conclude as follows:

Observations for GEO objects

The analysed strategies can be separated in to two main sets. The strategies with telescopes in LEO orbit and the strategies with the telescope passing close to GEO ring. The first set of strategies provides poorer results in terms of observable, observed and sensitivity system, because they are not so close as the other set of strategies. However, in terms of re-observation period and timeliness they provide proper performances. That means, that they are adequate for constructing and maintain a future GEO catalogue. But this catalogue will not contain very small objects. With the telescopes simulated in this work, objects up to 1.5-meter size are detected from LEO orbit. The sensitivity may be improved by changing the aperture and Field of View of the telescope. The strategies with the telescope close to GEO ring detect objects up to 7 cm (with the same sensors). However the high re-observation period and the high timeliness make these strategies not appropriated for constructing and maintaining a catalogue.

In general terms, LEOEQ and LEOSS2P are the better of the first set of strategies. LEOEQ provide slightly better performances in terms of sensitivity and re-observation period, but it has a mean of duration of the track very short. This fact may be an inconvenient for computing the initial estimation of the state vector. On the other and the pointing law of LEOSS2P presents two discontinuities. Therefore, that may cause problems for controlling the telescope and the general performances provided by LEOSS2P may decrease. Considering two telescopes in SSO solves this problem: one pointing at 20º with respect to the Earth-Sun line and the other pointing at –20º.

When a catalogue with very small GEO objects is required, then a constellation of telescopes in sub-GEO or in GTO objects must be considered. Depending on the cost limitations and the sensitivity requirements a constellation of many telescopes in sub-GEO (for a catalogue with very small GEO objects) or a constellation with two or three telescopes in GTO orbit, may provided the desired performances.

Observation for the rest of type of objects;

Space based telescopes for observing LEO objects are not adequated at all. Better performances are obtained with a ground-based radar.

For the rest of objects, strategies LEOEQ and LEOSS2P provide the better performances, although one telescope in GTO orbits also provide quite good performances.

AS4 simulator:

The analysis performed in this work has been completely performed by means of the Advanced Space Surveillance System simulator (AS4) developed by DEIMOS Space, under several ESA contracts. Moreover, the results presented in this paper are obtained during a project partially funded by the CDTI (Ministerio de Ciencia e Innovación -Spanish Government-).

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