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Improving geostationary orbits by the TWSTFT experience

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Abstract

Using data obtained by means of the TWSTFT experience, we try to improve some parameters of the orbit of geostationary satellite (we are now considering the communications satellite Intelsat 706) with better precision what will redound to a better economic profitable use of this satellites, since their life will be increased while the number of maneuvers will decrease. At the same time, it will be possible to increase the number of possible satellites standing at a preassigned area of a few kilometers on the equator.

Keywords: Tracking satellites, data analysis, propagation of orbits, geostatiory satellites

AMS Classification: 65L06, 70F15

1 Introduction

The difficulty of hunting brave red partridge is well known. In much aspects it may be compared with the tracking to artificial satellites. We can note that the fly of a partridge must be followed in real time, it suffers the atmospheric drag (the wind), it must fly-over the undulation of the ground (it is under the gravitational field), some times it disappears behind the bushes (periods of non observability, eclipses), an so on; while the hunter is not always well placed (reference frame definition) and his shaked breathing (movements of the station), their cold fingers delays the shooting, his gun is perhaps not well calibrated, and so on; all these thinks disturb the shoot.

The trajectories of the partridge and the satellite suffer similar perturbative effects, and, by the way, both trajectories are very regular. So, both problems have a lot of common characteristics. As in the hunting, tracking satellites requires an adequate preparation.

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Figure 1: Tracking a geostationary satellite.

The first step, in both jobs, is to put the feet on the ground, that is to say, to know what are we doing and for what purpose. That re uieres to know the behaviour of the used tools (numerical or analytical method of propagation of orbits, physical model, etc.), the approximation of the method versus the physical-mathematical model; and to have very clearly the specification required. For instance, in the satellite-to-satellite tracking (used to control some constellation of satellites) observations are obtained with a noise of about 1-10 mm/s, while the accepted error is 1 % over data; in this way, the needed requirements of precision are those shown in the following table 1

Table 1: Data precision in satellite-to-satellite tracking [1]

Required precision after 3 days		
	Absolute precision	Relative precision
Velocity	0.1 $\mu m/s$	$\approx 10^{-11}$
Position	0.1 mm/s	$\approx 10^{-11}$

The aims of this paper is to improve the orbits of geostationary satellites by improving the physical model, it is to say, obtaining a better estimation of the value of the parameters appearing in the model, mainly the zonal harmonic coefficients of the Earth potential. To develop this work we are considering the time and distance data obtained from the TWSTFT (Two-ways Satellite Time and Frequency Transfer) experience, and to analyze these data we have adapted and refreshed the software ORBIT10 [5] to our necessities.

2 The TWSTFT experience.

Some years ago, we initiated the task of improving the Earth potential model for its use with some Earth satellites [2, 3, 7]. To carry out this work we consider laser tracking to satellites data. Lately, our aim is related to geostationary satellites.

An essential question in this field is that the orbital dynamics and the precise positioning of this type of satellites are not well known: in fact, the orbits of HISPASAT satellites, for instance, are known with an uncertainty in the range of kilometers. To improve the orbit of geostationary satellites to the order of centimeters is one of our aims; this is of great interest for some companies involved with these satellites.

At present, the techniques used in the determination of position of geostationary satellites show a high uncertainty which compel to keep the closed up satellite (this is the case of Hispasat satellites) separated at about ten kilometer of distance; this causes, on the one hand, the necessity of maneuveringthe satellite very frequently, which reduces its live, and, on the other hand, it constrains the number of possible satellites standing at by in the assigned window, reducing the possibility of commercial exploitation.

Geostationary satellites are not specially technologically prepared for laser tracking; nevertheless, some of them (Intelsat, Hispasat, etc.) carry some transponders what, indirectly, make possible their use for this purpose by considering the TWSTFT technique.

The TWSTFT (Two-ways Satellite Time and Frequency Transfer) experience is being developing in some time laboratories for ten years. The Real Instituto y Observatorio de la Armada at San Fernando (Spain), with whon we have close collaboration, is the only Spanish laboratory furnished with equipment enabling this technique. This equipment consists, among others, on a clock giving the time with a precision of 10^{-9} seconds.

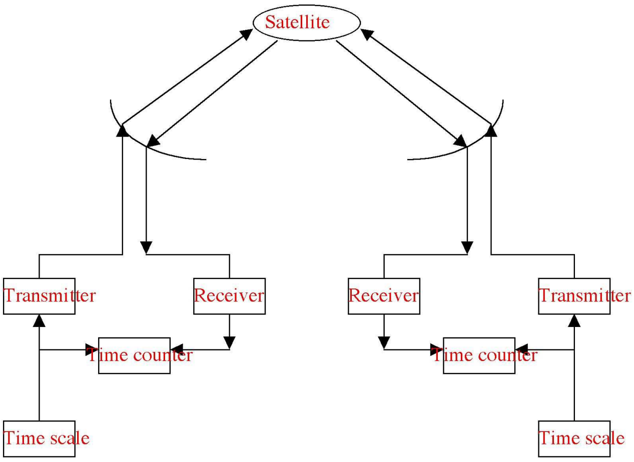

Figure 2: The TWSTFT principle

The TWSTFT technique implicates several laboratories and it consists, basically, in the simultaneous emission from two laboratories of time signal during programmed sessions, varying in mutual agreement the code of both stations. This temporal variation allows that at the end of each session all the stations can compare their time among them. In the figure 2 we can see an scheme of the process. The precision reached with this technique is in the neighboring of hundred of pico-seconds.

Due to the fact that the delays of the signal are changing with the distance, the ionosphere, the troposphere, the temperature, the Earth conductivity, etc., the TWSTFT technique has been introduced to eliminate the mentioned influences until first order. Both stations broadcast the time signal at the same instant and, in both sides, the signal of the other clock is received and measured. After the interchange of the received data, the difference between both clocks is calculated. Due to the reciprocity of both clocks, the delay can be eliminated until first order.

The precision of the results depends on the residual effects due to the incomplete reciprocity. Some of this effects are well known; for instance, the non reciprocity due to the equipment on the satellite, the Sagnac effect correction (caused by the motion of the satellite around the rotational axis of the Earth), the effect due to the motion of the satellite with respect to a fixed frame on the Earth, the ionospheric correction, the tropospheric correction, the correction due to the delay in each station because the converters, modulators, wireless, etc.

The instrumentation handled in the above mentioned technique allows the determination of pseudo-distance station-satellite in the order of 1.5 ns that is equivalent to 0.36 m. The determination of delays associated to the measure procedure of this pseudo-distance allows to know the distance station-satellite with an associated uncertainty.

The station-satellite distance is calculated three times per week almost simultaneously by three or more stations (currently, four stations) adequately selected and synchronized in time, what will enable the high precision determination of the position of the satellite. These distance measures, obtained as a collateral result when the clocks are compared, are calculated three times per week by the five station involved in the task, and transmitted via Internet to the BIPM and the other laboratories for their analyze.

More precisely, we are in the way of determining the position of the geostationary satellite Intelsat 706 and the values of the geodesical parameters with a better precision. This will redound to a better profitable economical use of the satellite, inasmuch its life will be enlarged as the number of maneuvers will decrease, and will allow to increase the number of stand by satellite in the assigned window.

3 Data analysis

Actually, our very interest is on the use of the obtained data more than on the technique itself. We performed the data analysis in the way that we biefly expose in the following.

First at all, it is necessary to have a previous orbit of the satellite, for which we take the initial conditions from the so called "two-line elements" referred to a reference frame, named TEME, using the true equator and the mean equinox of the epoch; we need a transformation to our reference frame of integration. It is also necessary to have refreshed the data basis with the position of the terrestrial Pole obtained from the IERS (International Earth Rotation Service), as well as the differences TAI-UTC.

A very important fact affecting the convergence of the process is that the orbit of the satellite is modified every week; so, our reference orbit must be a discontinuous one, each piece starting some time after the maneuver isdone, but close by.

In the second place, the obtained data must be assimilated to normal points and adequately grouped by arcs, and a file with an adequate format containing the assembled arcs must be edited for its later use. Let us remember that an arc is, in our context, a set of measures of time and distance (normal points) from each station. This task is done in an automatic way by means of the application "airbig", built up by us. After its running, from the data, there appear the files: `norarc.01` (containing the Julian date of the central point of the arc, seconds from the central point, distance to the station, number of the station and its associated weight), `metarc.01` (containing the meteorological data of the station), `locarc.01` (containing the position and velocity of the central point of each arc).

In third place, it is performed the orbit correction with the application "cobig". At its first running, where the "outliers" (thet is to say, the bad observations) are rejected, the residuals of data with respect to the previous orbit are obtained and the local parameters calculated (first approximation of the final position and velocity).

If the residuals are small enough, it can be considered a second iteration of the process. In this second iteration they are used to determine other global orbital parameters such as zonal and tesseral coefficients of the Earth potential, parameters involved in the perturbations (solar radiation pressure, atmospheric drag, etc.). To this purpose it is necessary to consider a very complete model of disturbing forces and a numerical propagator precise enough.

Due to the shortage of our current data, the residuals obtained in the first running is about a few kilometers; they are not good enough for converge of the process, thus it is necessary to wait for bigger data base that, by the way, is coming dayly in an automatic way.

3.1 Numerical aspects.

The package that we are using to perform the data analysis is a modification and adaptation, done by us, to the geostationary satellites of the software ORBIT10 developed at the University of Pisa [5]. This package is very involved; it is composed of more than 200 modules with some thousand of code pages. We will explain some aspects developed over there.

Equation of Kepler.

The resolution of Kepler's equation is required a lot of times along the execution of our software, specially every time we need Keplerian elements to describe the orbit of the satellite. The resolution of non-linear algebraic equations is also necessary if we use implicit Runge-Kutta methods (for instance, symplectic Geng's method) to propagate the orbit. For these reasons we have developed [8] a generalized Newton method that provides better efficiency than classical methods usually considered.

Ideal frame and regularization

The ideal frame, $\mathcal{I}$, [6] results from the "departure frame" rotated by

$$\boldsymbol{w}_{\mathcal{I}} = \frac{r}{G}(\boldsymbol{F} \cdot \boldsymbol{n})\boldsymbol{u},$$

with the usual meaning of the symbols. In this way, the ideal frame has instantaneously one coordinate plane coincident with the orbital plane, which supplies a few properties that make this frame specially interesting for numerical integration. With respect to this frame the equations of motion can be decompose into two non-independent parts: the motion of the orbital plane and the motion of the satellite on this plane.

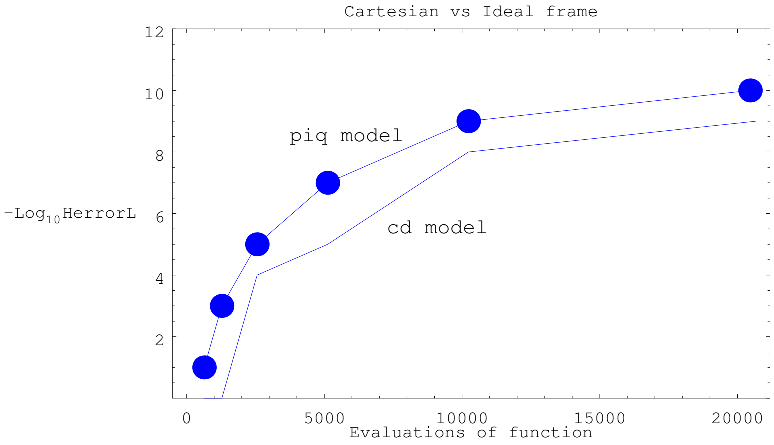

Figure 3: Curves of efficiency for h $= \pi/2^k$, $k = 2, 3, ..., 7$

Propagation of the orbit when the equations of motion are formulated in this frame provides results improving at least two digits the classical integration in Cartesian coordinates. We can see the figure 3 representing the curves of efficiency in the propagation of the orbit of a Skybridge satellite after 20 revolutions for the model of the equation in Cartesian coordinates and projective coordinates in the ideal frame; to obtain it we have used the symplectic propagator of Runge-Kutta-Geng of order 5 and different step-sizes. [4]

Numerical method:

For the propagation of the orbit, we have included in our software the already classical numerical Runge-Kutta methods of Dormand and Prince of order eight, and Cowell method in its formulation as linear multistep methods. Special mention must be paid to the considered method of Störmer-Cowell of high order and with some properties of symmetry; their behaviour has been studied by Quinlan and Tremaine [10] and have been found very adequate for the orbital propagation.

3.2 Geodesical aspects

The main perturbation to be taken into account in the analysis of orbits of geostationary satellites and that we have considered are: the Earth potential (only the harmonic until J_6), third body (Sun and Moon) attraction and Solar radiation pressure; other less relevant effect will be taken into account when very high precision must be obtained.

Determination of the parameters appearing in the expression of these perturbative effects as well as the position and velocity of the satellite and the position of the tracking stations are been performed in our group. The first results are no very good due to the low convergence of the process. When the series of data increases, we are confident that the results will improve very essentially.

4 Conclusions

The TWSTFT (Two-way Satellite Time and Frequency Transference) provide us with highly accurate data of time and distance of geoestationary satellite (Intelsat 706). The analysis of TWSTFT data will provide a better estimation of parameters appearing in the expression of these perturbative effects as well as the position of the tracking stations and position and velocity of the satellite. This improvement will reduce the number of maneuvers to be done on the satellite, what will redound in increasing the life of the satellite itself and, probably, will increase the number of possible satellites standing at a preassigned area of a few kilometers on the equator at geostationary position.

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References

[1] Balmino, G. and Barriot, J. B. *Numerical integration techniques revisited*, Manuscripta Geodaetica **15**, 1, 1–10, 1990.

[2] Blesa, F.; Palacios, M. and Ferrer, S. *Refinamiento de los primeros armnicos del potencial terrestre con medidas lser de satlites GPS.* I Asamb. Hispano-Portugesa de Geodesia y Geofsica, Almeria, 1998, pag. 52.

[3] Blesa, F.; Palacios, M. and Ferrer, S. *Improving the first harmonics of the Earth geopotential by using SLR data of Etalon and GPS satellites.* Proceeding XXV EGS Assambly, Nice, 1998.

[4] Geng, S. *Construction of high order symplectic Runge-Kutta methods*, J. Comput. Math., 11, 250-260, 1993.

[5] Milani A., Carpino M., Rossi A., Catastini G., Usai S. *Local Geodesy by satellite laser ranging: a European solution.* Manuscripta Geodaetica 20:123–138, 1995.

[6] Palacios, M. and Calvo, C. *Ideal Frames and Regularization in Numerical Orbit Computation.* J. Astronaut. Sci. **44**, n. 1, 63–77, 1996.

[7] Palacios, M.; Blesa, F. & Calvo, C. *Improving the Earth Potential Harmonics by Laser Data of Satellites in 2:1 Resonance.* J. of Geodesy, 2001. Submitted.

[8] Palacios, M. *Hacia una adecuada propagacin de rbitas.* IV Jorn. T. Mec. Cel, La Manga (Murcia), 2001. To appear.

[9] Palacios, M. *Kepler equation and accelerated Newton method*, J. Comp. Appl. Maths., **138**(2), pp. 335-346, 2002.

[10] Quinlan, G. D. & Tremaine, S. *Symmetric multistep methods for the numerical integration of planetary orbits*, Astron. J., **100** (5), 1694–1700, 1990.

[11] Rudenko, S. *Geosynchronous Satellite Orbit Determination*, in Dynamics and Astrometry of Natural and Artificial Celestial Bodies, Ed. I. Wytrzyszczak et al., p. 351-354, 1997.