POSTPROCESSED-TLE CATALOGUE FOR CONJUNCTION DETECTION WITH GEO PASSIVE OBJECTS

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ABSTRACT

This paper reports on a novel approach for the post-processing of TLEs to generate improved orbital information of inactive objects in the GEO regime. The paper describes briefly the methodology, a proof of concept test and the performances of the obtained orbital information by comparison against accurate CDMs, the current status of the enhanced TLE catalogue as routinely maintained by GMV, and two use cases of refined analysis of potential collisions involving GEO operational satellites using this catalogue.

Based on this concept, GMV is routinely generating a **catalogue** of **800 GEO inactive objects** with the orbital accuracy presented above. A *real example* of the use of the *postprocessed* TLE catalogue in real ***closeap*** collision reports has shown that the properties of the conjunction detected based on the *postprocessed* TLE ephemeris is much closer to that based on the CDM than with the TLE itself. In fact, miss distance and radial distance agree quite well between *postprocessed-TLE and CDM*-based detections.

This paper describes the method used for the generation of the postprocessed TLE catalogue and the performances achieved in terms of orbital accuracy and satellite collision prediction.

1 INTRODUCTION

Nowadays more than **2200 unclassified objects** are **transiting** the **GEO** region. Out of those, almost **1300 objects orbit** in the **GEO** region, and, in turn, out of those, more than **400 objects** are **active** satellites, being **space debris** the remaining **800 GEO objects**. Regarding GEO active objects, operators and agencies usually share orbital information to avoid collisions among them. This is for instance the case of the Space Data Association (SDA) and its Space Data Centre (SDC). Thus, the largest remaining thread to GEO satellites comes from inactive GEO resident space debris objects. For those inactive objects the only information publicly available in a routine manner are JSpOC TLEs.

A **network of sensors** plus the corresponding on-ground processing can be used to improve the orbital knowledge of those inactive objects in order to refine the knowledge of upcoming conjunctions. On the other hand, a much cheaper alternative to the use of telescopes is the post-processed TLE GEO catalogue. The idea behind the **post-processed-TLE GEO catalogue** is to obtain space debris orbits at GEO altitude as accurate as possible using only publicly available TLEs. The postprocessed-TLE catalogue concept is based on the combination of two main factors: a) our deep knowledge of the dynamics of inactive objects at GEO altitude; and b), the existence of large data sets of publicly available Two Line Elements (TLEs) from JSpOC.

2 METHODOLOGY

On the one hand, GEO passive objects have well-known orbital dynamics defined mostly by the Earth gravity, Moon and Sun gravity and solar radiation pressure. On the other hand, JSpOC publishes routinely Two Line Elements (TLEs) of those objects. Thus, it is possible to combine several of those TLEs for the same object in order to obtain improved orbital information. This can be achieved through a typical batch-least squares orbit determination process, where the measurements correspond to XYZ positions generated based on TLEs with the Simplified General Perturbations (SGP) theory, and the parameters to estimate correspond to the state vector of the object (position and velocity at epoch), extended with the solar radiation pressure coefficient (assuming certain default mass and solar radiation pressure area for the object).

In order to obtain the most accurate results from this process the following aspects have been considered: **time interval used for each TLE relative to each TLE epoch**, and **length of the overall orbit determination arc**. These two aspects are analysed in detail next.

It is well known that the **accuracy of the position** derived from TLEs with the SGP theory depends to a great extent on the time relative to the TLE epoch. Thus, in order to obtain the best possible results from the combination of several TLEs in the orbit determination process, the XYZ pseudo-observations generated from each TLE must correspond to the time interval where

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the TLE is most accurate. Due to the way how TLEs are generated, it is expected that this interval corresponds to several days before the TLE epoch.

Regarding the length of the time interval used for the parameter estimation process, it is well known from the theory of orbit determination processes that this length must be chosen from a trade-off between the accuracy of the dynamical models and the accuracy of the measurements. In principle, the longer the orbit determination arc is, the more accurate the resulting orbit is. This is due to the fact that the longer the arc is, the more information is input into the determination process. However, there is a point where the dynamical models used are not accurate enough to model the orbit with an accuracy equivalent to that of the pseudo-measurements used. In our case, XYZ pseudo-observations derived from TLEs are expected to be few km accurate. Our analysis shows that orbit determination arcs of several weeks are adequate to this respect in the GEO regime. Tests have been performed with a varying number of weeks, looking at the RMS of the orbit determination process. The point when the orbit determination arc should not be further increased can be detected as the point when the RMS of the orbit determination process starts increasing noticeably. This indicates that the dynamical models used can no longer cope with the accuracy of the measurements due to the excessive length of the arc.

3 PROOF OF CONCEPT TEST

In order to show the accuracy of the method developed to generate the post-processed TLE catalogue, a proof of concept test has been carried out. This test consists on the generation of predicted orbits of around 800 inactive GEO objects using as input only the TLEs from JSpOC available up to the date of prediction. As external information, orbital states from CDMs have been used as a way to check the accuracy of the predicted orbits.

The following features are worth mentioning about the proof of concept test:

- **Analysis time span**: July'14-Apr'15
- **Analysis input information**: only public TLEs
- **Analysis population**: around 800 GEO inactive objects
- **End product**: predicted orbits of GEO inactive objects
- **Use case** analyzed in detail for which a specific tracking campaign with telescopes has been performed

Figure 1 shows as a function of the time to TCA the position covariance reported in the CDMs at the TCA (left figure), the difference between the enhanced TLE catalogue orbits and CDM states at TCA (right figure) as well as the same statistic for orbits propagated from TLEs with the SGP theory (centre figure). These figures have been obtained from an analysis of 600 CDMs.

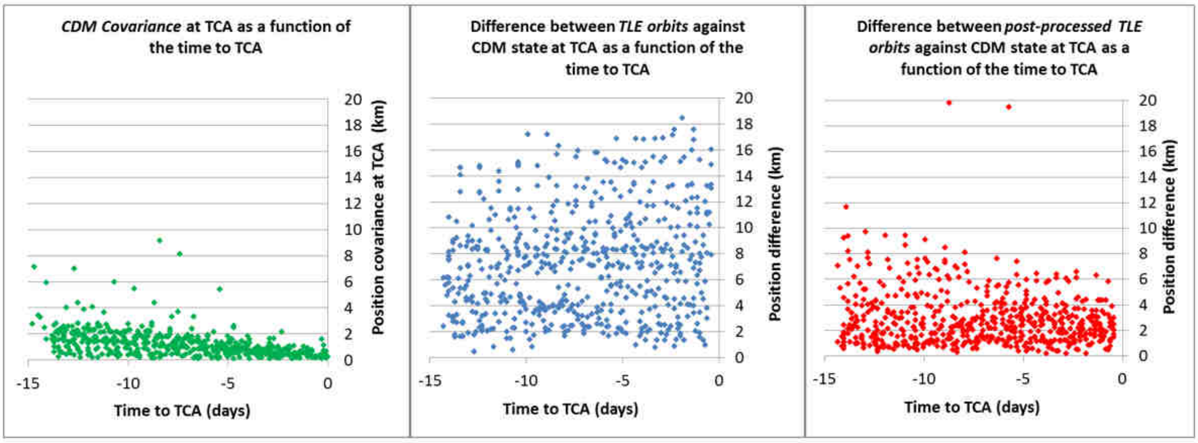

Figure 1: Comparison of orbital states at TCA from CDMs (left), enhanced TLE catalogue (centre) and TLEs (right)

The following conclusions can be drawn from the proof of concept test:

- Uncertainties reported in the CDMs involving GEO objects are normally below 3 km, with a typical value around 1 km, and decrease linearly as the TCA approaches.
- Orbital states derived from TLEs at TCA have errors with an average of 8 km and can reach up to 20 km regardless of the time to TCA.
- Orbital states at TCA derived from GMV's enhanced-TLE catalogue have errors with an RMS of 3-4 km and decrease linearly as the time to TCA decreases, similarly to the covariance reported in the CDMs.
- In average, we can conclude that **GMV's enhanced-TLE** catalogue allows obtaining orbits **3-4 times better than TLEs** and only 2.5 times worse compared to CDM reported covariances.

A second proof of concept test in a real conjunction case was also performed. The test consists in the analysis of a high-risk collision with GEO space debris in October 2014. The following points are worth mentioning about this test:

- The accuracy of orbital state reported in the **best CDM** is **0.9 km 1-sigma**, and in the **earliest CDM** is **2.5 km 1-sigma**
- The difference between the state derived from the **TLE** released **2 days** before the conjunction and the orbital state at TCA in the **best CDM** is **10 km**
- The difference between the **restituted orbit** based on the post-processing of TLEs up to 2 days before the event and the orbital state at TCA in the **best CDM** is **1.6 km**
- The difference between the **restituted orbit** based on TLEs up to two days before the event and the orbital state at TCA derived from a **specific tracking** campaign using telescopes is **1.2 km**

This test shows that the use of the post-processed TLE catalogue generated by GMV is very useful for collision risk analyses in the GEO region. It can be used as a way to obtain refined information about an upcoming collision event at a very reduced effort. The refined analysis performed with the post-processed TLE catalogue allows to obtain better information to decide whether an optical tracking campaign is necessary or even if a collision avoidance manoeuvre needs to be executed.

4 CURRENT STATUS OF THE CATALOGUE

The current status of the post-processed TLE catalogue is described next:

- The enhanced TLE catalogue is currently being **generated automatically by GMV in a daily basis** with the ***sstod*** software (SST orbit determination).
- The total amount of objects is close to **800 objects**, all of them in the GEO region. This corresponds to **all objects** with a **mean motion** between **1.08** and **0.92** rev/day**.**
- The provided ephemeris files are in **CCSDS** standard ASCII **OEM** and **OPM** format, including formal covariances obtained from the orbit determination process.

5 USING THE ENHANCED TLE CATALOGUE FOR COLLISION RISK

The following figures show two real examples of the use of the post-processed TLE catalogue in real ***closeap*** collision reports. These collision reports show conjunctions detected using the operational orbit (OPS), TLEs (TLE), enhanced TLE catalogue (TLE+) and JSpOC CDMs (CDM). In all cases it can be observed that the conjunction detected based on the enhanced TLE ephemeris is much closer to that based on the CDM than with the TLE itself. In fact, miss distance and radial distance agree quite well between the enhanced TLE and CDM-based detections (< 1 or 2 km), in line with the figure shown in the previous section.

Id	Target	Chaser	Target Src/Age	Chaser Src/Age	TCA	Miss Dist (km)	Collision Prob	Max Collision Prob	Rad Dist (km)	Along Dist (km)	Cross Dist (km)	High Risk
498		COSMOS 1894	OPS/ 3.2	TLE/ 1.3	2016/06/26-07:30:50	43.572	5.826E-008	1.944E-004	-5.299	-42.895	-5.518	
493		COSMOS 2209	OPS/ 3.2	TLE/ 2.1	2016/06/26-10:43:36	28.019	1.007E-012	3.023E-004	17.701	-21.518	-2.955	
			OPS/ 3.9	TL+/ 1.3	2016/06/26-10:43:34	24.718	0.000E+000	3.426E-004	20.748	-13.305	-1.864	
			OPS/ 3.2	CDM/ 1.1	2016/06/26-10:43:34	24.592	0.000E+000	1.726E-004	19.996	-14.179	-1.979	
492		COSMOS 2209	OPS/ 3.2	TLE/ 2.1	2016/06/26-10:43:54	12.617	3.271E-008	6.712E-004	5.875	-11.065	-1.492	
			OPS/ 3.9	TL+/ 1.3	2016/06/26-10:43:52	9.376	0.000E+000	9.033E-004	8.920	-2.860	-0.411	
			OPS/ 3.2	CDM/ 1.1	2016/06/26-10:43:53	8.996	0.000E+000	4.719E-004	8.168	-3.732	-0.525	
			CDM/ 0.1	CDM/ 1.1	2016/06/26-10:43:53	8.364	3.578E-094	1.819E-004	8.207	-1.596	-0.240	
496		COSMOS 2209	OPS/ 3.2	CDM/ 1.1	2016/06/26-10:44:45	44.393	0.000E+000	9.562E-005	7.883	-43.301	-5.797	
			OPS/ 3.9	TL+/ 1.3	2016/06/26-10:44:45	43.677	0.000E+000	1.939E-004	8.634	-42.435	-5.688	
			CDM/ 0.1	CDM/ 1.1	2016/06/26-10:44:17	6.808	6.794E-092	7.310E-004	5.845	3.463	0.449	

*Figure 2: **closeap** collision report for collision #1 (Target satellite id is omitted for confidentiality reasons)*

Id	Target	Chaser	Target Src/Age	Chaser Src/Age	TCA	Miss Dist (km)	Collision Prob	Max Collision Prob	Rad Dist (km)	Along Dist (km)	Cross Dist (km)	High Risk
486		ASC 1	OPS/ 1.3	TLE/ 1.3	2016/06/12-13:14:22	15.866	3.479E-026	5.338E-004	-13.850	-7.678	-0.970	
			OPS/ 2.1	TLE+/0.0	2016/06/12-13:14:23	20.712	2.784E-011	4.089E-004	-14.758	-14.416	-1.833	
			OPS/ 1.3	CDM/ 0.2	2016/06/12-13:14:23	19.432	0.000E+000	2.174E-004	-14.855	-12.427	-1.577	
489		ASC 1	OPS/ 1.3	TLE/ 1.3	2016/06/13-13:10:15	38.149	2.265E-024	2.220E-004	-14.037	35.180	4.554	
			OPS/ 2.1	TLE+/0.0	2016/06/13-13:10:16	32.421	2.720E-010	2.612E-004	-14.983	28.513	3.691	
			OPS/ 1.3	CDM/ 0.2	2016/06/13-13:10:16	34.376	0.000E+000	1.229E-004	-15.087	30.633	3.963	
488		ASC 1	OPS/ 1.3	TLE/ 1.3	2016/06/14-01:08:07	9.341	2.197E-009	9.067E-004	4.799	-7.945	1.044	
			OPS/ 2.1	TLE+/0.0	2016/06/14-01:08:08	15.423	4.701E-008	5.491E-004	5.773	-14.179	1.870	
			OPS/ 1.3	CDM/ 0.2	2016/06/14-01:08:08	13.419	0.000E+000	3.148E-004	5.853	-11.972	1.577	
			CDM/ 0.2	CDM/ 0.2	2016/06/14-01:08:10	6.454	1.643E-010	3.582E-004	6.404	0.798	-0.116	

*Figure 3: **closeap** collision report for collision #2 (Target satellite id is omitted for confidentiality reasons)*

6 CONCLUSIONS

The following conclusions can be derived from the analyses presented above:

- A new concept for the **reconstruction of GEO space debris orbits** based **only** on publicly available TLEs has been presented.
- **Accuracy** metrics of resulting orbits are **much better** than the **TLEs**, and **close** to the **CDMs**.
- This concept is used by GMV to generate a **catalogue of GEO region space debris orbits** of an accuracy comparable to CDMs.
- Main **advantage over CDMs**: availability of complete ephemerides for all GEO space debris objects

The application of this approach has been recently extended by GMV to **LEO objects**. In this case, the goal of the TLE post-processing is not the refinement of collision events, as the accuracy required for such analyses is much better than what can be achieved based on TLEs. The objective is indeed the refinement of **re-entry predictions of uncontrolled objects** contained in the JSpOC catalogue. The very same approach can be used but has required fine tuning of the main parameters of the process to the LEO regime. This includes both the adjustment of the length of the orbit determination arc, and the time interval used for each TLE relative to the TLE epoch.