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A particle filtering method for the opportunistic update of a space debris catalogue

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ABSTRACT

The large increase in the amount of debris orbiting our planet has become a problem for present and future space missions. Space debris is mainly composed of inactive satellites, rocket bodies and pieces of both detached by collisions. The number of spacecrafts has grown in a sustained manner since the 1950s and, as a consequence, debris created by fragmentation of large satellites has increased at a very fast rate. Currently, the number of objects resulting from fragmentation duplicates the number of inactive satellites and rockets. Approximately 20,000 pieces of debris larger than a softball ($\approx$ 10 cm) have been catalogued and it is believed that more than 2 million objects with a diameter larger than 2 cm orbit the Earth. Actively tracking all these objects is a very expensive task in terms of time and resources. A method to propagate uncertainties into the future up to a new programmed or expected observation in a reliable way is needed to compensate the lack of continuous tracking.

In recent years, several attempts have been made at incorporating probabilistic tools for propagating uncertainties in orbital mechanics [1, 5, 4]. Among the latter, particle filters (PFs) [3, 2] stand out because of their flexibility and generality. PFs are sequential Monte Carlo methods used for Bayesian statistical inference in dynamical models. To be specific, they aim at constructing empirical (sample based) approximations of the probability distribution of the dynamic state variables conditional on the available observations. PFs consist of two stages: a *prediction* step, where the dynamical model is employed to generate candidate state values (often termed *particles*), and an *update* step where the observed data are used to weight these particles according to their likelihood. PFs are well suited for nonlinear tracking problems and, in particular, they appear as very promising tools for tracking space debris.

We introduce a PF-based methodology that allows, on the one hand, to update the orbital parameters of pieces of space debris when they are sparsely observed and, on the other hand, to reveal previously uncatalogued objects orbiting the Earth. The dynamics of each piece is represented in terms of six (time-varying) orbital elements, namely its angular momentum (h),

	500 particles	10^4 particles
FAR	0.048	0.048
MDR	0.085	0.057

Table 1: *False alarm rates (FAR) and missed detection rates (MDR) for a computer experiment with synthetic data generated from the TLE catalogue.*

eccentricity (e), true anomaly (ν), ascending node (Ω), inclination (i) and perigee (ω). The proposed method starts from a catalogue of objects and it takes advantage of opportunistic (and possibly heterogeneous) celestial observations in order to

(a) identify new objects to be added to the catalogue and

(b) to compute and update a probability distribution for the orbital elements $(h, e, \nu, \Omega, i, \omega)$ associated to each catalogued object.

The scheme is designed to maintain and update a large-scale catalogue of objects, as the computational algorithms needed are easily parallelisable. We employ efficient PF-based techniques to perform data association (i.e., to link each celestial observation to a subset of pieces of debris), to detect new objects, and to generate and update empirical probability distributions for the orbital elements of the catalogued objects. The latter enable us to estimate and predict the complete orbit around Earth of an object at any given time. The estimates can be endowed with expected errors of various types (covariances, collision risks, prediction errors, ...) which are easily computed from the empirical distributions generated by PFs.

We have assessed the validity of the method in a set of numerical experiments using both synthetic and real (publicly available) data. As a preview of our numerical results, Table 1 shows the false alarm rate (FAR) and the missed detection rate (MDR) for a computer experiment involving the assimilation of 126 observations synthetically generated from a set of 40 objects (30 of them catalogued). The attained FAR is $\approx 5\%$ and the MDR is $\approx 8.5\%$ (when using 500 particles in the PFs) but can be reduced to $\approx 5.7\%$ by increasing the computational effort (by generating 10,000 particles per PF).

References

[1] Kyle J DeMars, Robert H Bishop, and Moriba K Jan. A splitting Gaussian mixture method for the propagation of uncertainty in orbital mechanics. *Spaceflight Mechanics*, 140, 2011.

[2] P. M. Djurić, J. H. Kotecha, J. Zhang, Y. Huang, T. Ghirmai, M. F. Bugallo, and J. Míguez. Particle filtering. *IEEE Signal Processing Magazine*, 20(5):19–38, September 2003.

[3] J. S. Liu and R. Chen. Sequential Monte Carlo methods for dynamic systems. *Journal of the American Statistical Association*, 93(443):1032–1044, September 1998.

[4] Alinda Mashiku, James Garrison, and J Russell Carpenter. Statistical orbit determination using the particle filter for incorporating non-Gaussian uncertainties. In *AIAA/AAS Astrodynamics Specialist Conference*, page 5063, 2012.

[5] James Woodburn and Sergei Tanygin. Detection of non-linearity effects during orbit estimation. *Paper AAS*, pages 10–239, 2010.