Generalised Polynomial Chaos Based Particle Filter for Orbit Determination

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Due to the large number of resident space objects (RSOs) and the limited number of sensors available to track them, space surveillance is subject to large observation gaps. In addition, the large propagation intervals coupled with nonlinear RSO dynamics results in highly non-Gaussian probability distribution of the orbital state. Therefore, only filters which can handle both non-linear and non-Gaussian (NLNG) problem are suitable for orbit determination (OD) for these RSOs. Particle Filters (PFs) are useful for state estimation for NLNG systems. In the generic PF algorithm, however, the transformation probability density function (PDF) is usually given empirically. A simple assumption of Gaussian PDF always fails for RSO OD, which leads to deterioration of both the orbital state estimation performance and the uncertainty propagation. Also, due to the sequential Monte Carlo Simulation (MCS) essence, PFs generally need highly computational costs.

For these reasons, the main idea of this paper is to combine the generalised polynomial chaos (gPC) with PFs in a hybrid scheme, in order to achieve accurate OD but also increase efficiency. The gPC theory is proposed to account for the effects of arbitrary, time-invariant uncertainties associated with model parameters and initial conditions. It has been proved to be more efficient than MCS method for uncertainty propagation. In this work, gPC is used to propagate the orbital state with uncertainties through the non-linear dynamics. With coefficients of gPC, the moments (e.g., mean, covariance, skewness and etc.) of the orbital state can be calculated, which are used for approximating the transformation PDF based on the maximum entropy principle (MEP). Then a generic PF scheme is implemented for the posterior orbital state and PDF estimation. The basis polynomials of gPC need to be regenerated based on the posterior PDF for the next iteration. Finally, numerical simulations are given for testing the OD performance by the proposed gPC-PF algorithm with ground-based observations. Its performance is compared with extended Kalman filter (EKF) and generic PF, in terms of uncertainty analysis, state estimation and computational efficiency. Preliminary OD results are shown in Figure 1 and statistic values of OD errors are given in Table 1. It is clearly shown that OD performance by PFs outperforms than that by KF. gPC-PF gives similar position estimate and better velocity estimate in terms of 3D RMS (Root Mean Squares) errors with respect to the traditional PF. More OD scenarios will be conducted before solid and convincing conclusions are drawn.

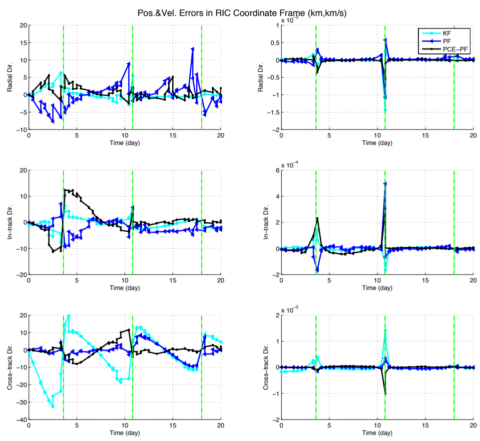

Figure 1 RSO position & velocity errors in RIC coordinate system

Table 1 Maximum values of each component and 3D RMS errors (km, 1.0^{-3}km/s)

	P_R	P_I	P_C	P_{3D}
KF	6.319	7.608	32.675	12.696
PF	13.163	9.336	9.521	6.255
gPC-PF	5.566	12.412	11.628	6.456
	V_R	V_I	V_C	V_{3D}
KF	1.440	0.167	1.416	0.282
PF	1.072	0.498	0.342	0.172
gPC-PF	0.551	0.308	1.016	0.156