Uncertainty Propagation and Nonlinear Filtering for Space Navigation using Differential Algebra

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Nonlinear uncertainty propagation and filtering play an important role in various space-related applications, especially in orbit determination and navigation problems. Near future sample and return missions from small bodies, landing missions to the Moon, Mars and outer planets as well as interplanetary exploration missions demand navigation systems based on accurate filtering techniques able to perform accurate trajectory estimation in a very reduced lapse of time.

Differential algebraic (DA) techniques are here presented as a valuable tool to face this problem. Working in the DA framework enables a general approach to perform uncertainty propagation through any nonlinear transformation such as complex nonlinear dynamics or coordinate transformations that can enhance and speed up classical uncertainty propagation methods, i.e. Monte Carlo simulations or higher order estimation schemes. Differential algebra can also be used in nonlinear filtering for state determination in order to obtain filtering schemes characterized by reduced computational burden with respect to classical nonlinear filters such as particle filter or higher order extended Kalman filters but without loosing accuracy.

The performance of the proposed DA-based uncertainty propagation methods and filtering techniques has been checked and critically analyzed by numerical simulations run on different test cases and orbit determination problems.