Assessment of onboard DA state estimation for spacecraft relative navigation

Executive Summary

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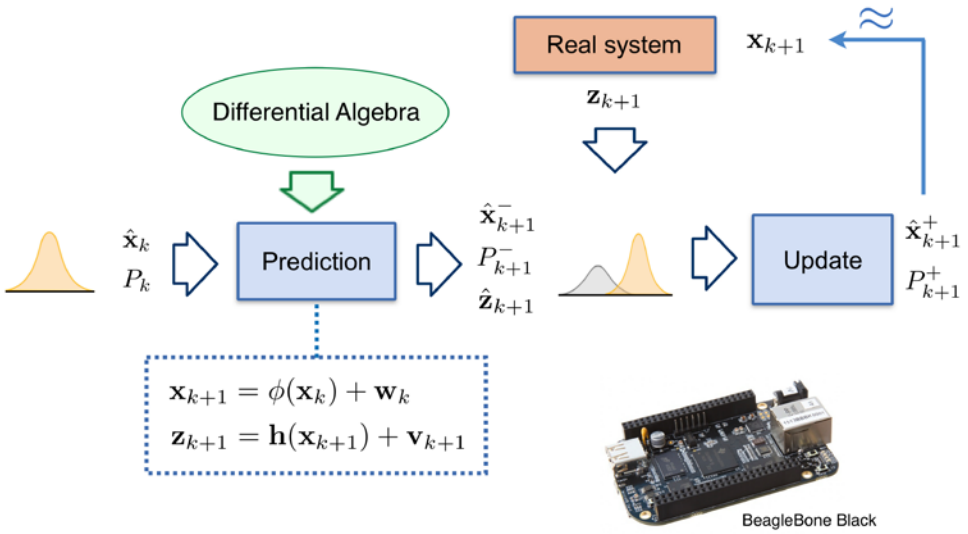
Picture:



Motivation:

The goal of this study is two-fold. First, to identify and develop a DA-based high-order filter for relative pose estimation. The application considered is the rendezvous with an uncooperative target, modelled after ESA's e.deorbit mission. Secondly, the DA algorithms are implemented on hardware mimicking the limited computational power available in space. The resulting implementation is tested in a processor in the loop (PIL) test-bench using the approach phase of the chaser to the uncooperative target to be estimated.

Methodology:

At the present time the extended Kalman filter (EKF) is the main algorithm used for trajectory estimation. The EKF is based on the main idea of linearizing the equations of motion and the measurement equations via first-order Taylor expansions around the current mean and covariance.

In some cases, however, the linear assumption fails to provide an accurate realization of the local trajectory motion. In such cases, a different method that accounts for the system nonlinearity must be used. Unscented Kalman filter (UKF) yield superior performance with respect to the EKF in highly nonlinear situations. However, in practice, the UKF is often slightly slower than the EKF. In 2007 Park and Scheeres developed a nonlinear filter named higher-order numerical extended Kalman filter (HNEKF) by solving for the higher-order Taylor series terms. These higher-order filters are more accurate than the EKF but require the derivation of the higher-order tensors.

The calculation of these tensors is straight forward using Differential Algebra techniques. This eliminates the need to calculate the higher-order tensors. An open question is how the computational overhead associated to the calculation of the polynomials affects its applicability to onboard applications.

In this work we implement a pure C version of the DA core engine, and then assess its performance and onboard applicability of the DA-based HNEKF algorithm with the target application of estimating the relative pose between two spacecraft during a rendezvous manoeuvre. The assessment is performed on a BeagleBone Black embedded platform, similar to future space computational platforms.

Results:

- A pure C version of the Differential Algebra Core Engine has been developed and released as opensource software
- A proof of concept for an autocoder for converting C++ DACE code to pure C code has been developed
- A DA based high order Kalman filter has been developed and applied to the rendezvous problem
- A performance analysis of the implementation on space-relevant hardware has been carried out

Publications:

- Cavenago, F., Di Lizia, P., Massari, M., and Wittig, A., “On-board DA-based state estimation algorithm for spacecraft relative navigation”, to be presented at the 7th European Conference for Aeronautics and Space Sciences, 3-6 July 2017, Milan, Italy
- Massari, M., Wittig, A., Cavenago, F., Di Lizia, P, Differential Algebra software library with automatic code generation for space embedded applications, abstract submitted to the AIAA Science and Technology Forum and Exposition (AIAA SciTech 2018), 8-12 January 2018, Gaylord Palms Kissimmee, Florida, USA
- Cavenago, F., Di Lizia, P., Massari, M., and Wittig, A., “On-board high-order Kalman filtering for relative pose estimation during rendezvous with an uncooperative target”, to be submitted to the Journal of Guidance Control and Dynamics

Highlights:

Based on the results of the performance analysis of the high-order filter obtained within the study, the Team is currently working on the development of alternative filters that can better benefit from the high-order partials provided by differential algebra. More specifically, the Team is currently implementing a DA-version of an Unscented Kalman Filter

and is working on the development of a new filter that exploits high-order moments in the prediction and update steps.