Numerical Methods for State Estimation in Highly-Nonlinear Mechanical Systems: A Case Study

Mikhail Shavin*, Dmitry Pritykin†

* Moscow Institute of Physics and Technology
9 Institutskiy per., Dolgoprudny,
Moscow Region, 141701, Russian Federation
e-mail: shavin@phystech.edu, web page: http://www.mipt.ru/

†Skolkovo Institute of Science and Technology
Nobelya Ulitsa 3, 121205, Moscow, Russian Federation
e-mail: dpritykin@rambler.ru

ABSTRACT

We revisit the problem of state estimation in nonlinear dynamical systems, which remains one of the key engineering tasks in applied control theory. Ours is a specific case of a tilt-rotor quadrotor control system design. The tilt-rotor quadrotors have become a point of interest in the UAV field because of their overactuation, which, on the one hand, promises better controllability and maneuverability of the system, and yet, on the other hand, entails essential nonlinearities in the model of the vehicle's dynamics. This nonlinearity calls for a thorough study of the state estimation algorithms, which then can be used in the control loop.

As of today, there is no accepted single strategy that outperforms all other solutions, as every nonlinear system may be said to be nonlinear in its own way. Thus each application requires selecting the estimator which provides the best trade-off between various characteristics such as estimation accuracy, numerical robustness, and computational intensity.

Without giving detailed desciption of the previously published dynamical model of the tilt-rotor quadrotor [1] and the controller design, we focus on the comparison of the state vector (comprising position, velocity, attitude quaternion, and angular velocity of the quadrotor) estimates by the widely used Extended Kalman Filter (EKF), Unscented Kalman Filter, and Cubature Kalman Filter. Several regimes of the quadrotor's controlled flight are employed, and the three implementations of the filters are found quite competitive, each having its own advantages and disadvantages. The paper discusses the particular properties of these algorithms' implementation, their robustness for different combinations of the UAV's states, measurements models, and the control cycle time.

REFERENCES

[1] Shavin, M. *Design and identification of tilt-motor quadrotor control system.* (2018) MATEC Web of Conferences, 211, art. no. 02013