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Review report on the doctoral thesis of Mr. Hamza Benzerrouk: "Modern Approaches in Nonlinear Filtering Theory Applied to Original Problems of Aerospace Integrated Navigation Systems with non-Gaussian noises"

As Official Opponent for the aforementioned thesis, I would like to provide my preliminary assessment.

The thesis of the Mr. Hamza Benzerrouk is devoted to nonlinear estimation under non-Gaussian noise distributions, with application to multiple positioning and navigation problems. One of the main topics in this dissertation has been the direct integration between inertial sensors and satellite-based positioning in denied-GNSS conditions.

An important point has been the consideration of a non-Gaussian measurement noise following a Gaussian mixture, which defines an alpha-stable impulsive noise. This distribution had not been solved before for navigation purposes and particularly in navigation filters although it had been widely investigated for interference in telecommunication channels and in multiple radar applications. In the dissertation, a solution is proposed based on a robust Gaussian mixture Cubature Kalman filter (CKF) and its adaptive form is implemented in the navigation filter of sensor fusion. Different scenarios have been simulated and experimented using real UAVs, then using an IRIDIUM receiver integrated with a GPS tracking system. In parallel, an approximated CRLB based on the Kullback-Leibler algorithm for nonlinear Gaussian mixture filtering has been developed.

The candidate has provided a solid comparison of non-linear filtering methods, including classical algorithms and modern approaches such as the Cubature Kalman filter and the Gauss Hermite Kalman Filter. Different implementations based on the innovation matrix and on adaptive algorithms have been proposed to transform these methods into fast convergence approaches, especially during poor initialization of the non-linear filters.

On the other hand, when measurements are affected by impulsive noise, Gaussian sum filters based on the adaptive CKF have provided the best performance when compared to Approximated Cramér-Rao Lower bound on the basis of the Kullback-Leibler reduction algorithm. Different algorithms have been proposed after the selection of the CKF as the best estimator for multiple navigation problems, such as the Gaussian Mixture Cubature Kalman Filter, the Gaussian Mixture Extended Kalman Filter, the Gaussian Mixture Adaptive Cubature Kalman Filter and the Gaussian Mixture Adaptive Extended Kalman Filter. These parallel approaches are potentially realistic solutions in terms of computational complexity for DSPs and FPGAs.

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A geometrical algorithm has been proposed to initialize the different developed filters in static scenarios. The algorithm serves also as an initialization step for the dynamic Iridium-based positioning. This solution is a challenging and a very attractive one for emergency situations in the ocean, desert and also for aircrafts in distress situation.

Finally, the Candidate has published abstracted and indexed publications (Scopus, ISI) and also reference Russian journals, which definitively proves the level of the presented results.

To conclude, I recommend proceeding with the public defense towards a degree of Doctor of Philosophy in Applied mathematics and Complex Information Computing and I have no reservation in stating that the thesis is PhD-worthy.

Sincerely yours,

Prof. Gonzalo Seco-Granados

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