Review's letter

on the PhD thesis of the candidate Hamza Benzerrouk

"Modern Approaches in Nonlinear Filtering Theory Applied to Original Problems of Aerospace Integrated Navigation Systems with non-Gaussian Noises"

The thesis of Hamza Benzerrouk carries out interesting and novel results with strong mathematical tools related to nonlinear estimation theory and especially based on Kalman filtering theory and estimation algorithms. The candidate has developed adaptive and robust algorithms based on modern approaches in nonlinear filtering theory such as new nonlinear transformation called Sigma Point Kalman Filter (SPKF) and Cubature Kalman Filter (CKF) with also Gauss-Hermite-Kalman Filter (GHKF). Novel algorithms based on adaptive fading and innovation based adaptive factor are developed, simulated and compared according Mean Square Error (MSE). Different steps and initialization conditions are checked in order to achieve and demonstrate the limitations of the classical forms of nonlinear filtering approaches including modern algorithms CKF and SPKF. Other techniques called interpolation filters such as DD1 and DD2, Divided Difference Kalman Filter at the first order and at the second order approximation using Stirling polynomial have been also proposed in the thesis. One of the main advantage is the opportunity to avoid computation of the Jacobian/Hessian matrices.

In parallel to this section, an elegant approximation of Cramer-Rao lower bound is proposed on the basis of the Extended Kalman filter for nonlinear Gaussian estimation problem with application to INS/GNSS and other sensors integration for multiple aerospace missions (robots, flight,..etc). This lower bound is used to select the best algorithm after a large selectivity tests done by the candidate and through with Cubature Kalman Filter CKF chosen as the most accurate and with acceptable computational complexity for real time application. It beats Gauss Hermite Kalman Filter GHKF which is the best estimator according MSE and RMSE criteria but by generating 1000 times number of cubature points to achieve slightly better estimation. Both CKF and adaptive CKF are selected for the next developments.

Then, when the problem of non Gaussian estimation problem with nonlinear system and measurement occurs, the candidate propose to solve the problem using Gaussian Sum Filtering approach by replacing the well known Multiple Linearization approach with Multiple Cubature Kalman Filters which has carried out the Gaussian Sum based Cubature Kalman Filter as a first solution. Then, with the assumption that the non-Gaussian is impulsive , with alpha stable pdf and with time varying parameters, an interesting combined solution of adaptive CKF and Gaussian Sum Filtering is then developed and proposed by the candidate with attractive results in simulation. So, the steps followed by the candidate proved the intuitive results and provide the best estimator in the case of nonlinear estimation with additive non-Gaussian impulsive noise following the model of Alpha-Stable noise density of probability function. To verify the results, different applications starting from UAV autonomous navigation, pedestrian navigation problem and robot navigation with multiple sensors fusion are used in the thesis to validate all the results.

An approximation of the lower bound is proposed by the candidate on the basis of Kullback-Leibler reduction algorithm in order to approximate the Gaussian mixture with Gaussian density and then apply the first approximation related with the Gaussian estimation. At the end, in order to prove why such transformations are needed and why the proposed solutions are realistic, the candidate has provided the real existence of impulsive noises affecting Iridium Satellite based localization receiver which is used primary as a satellite telecommunication device but also provides Latitude and Longitude of the receiver with 1-10Km accuracy on the surface of the earth. This solution is presented as backup solution to GPS/GNSS positioning systems during jamming, spoofing or missing periods. In this case, such as for deterministic approaches, the candidate proposes to use deterministic geometrical algorithm for nonlinear filters CKF initialization and also Gaussian Sum CKF and its information version to initialize the static positioning algorithm. Finally, it is possible to deduce a new mathematical problem statement wihc consists on how determine geographical position on the basis of one satellite. Such solution could be certainly a generator of multiple applications in aerospace and probably for future exploration mission using restrictive number of satellites such for Mars exploration.

Finally, it is worth mentioning that the number of published papers includes more than 37 publications with high ranked abstracted papers and also indexed in recognized databases such as (VAK, Scopus, ISI).

My final evaluation is that the candidate Mr.Hamza Benzerrouk deserves the degree of Doctor of Philosophy in Mathematics.

Official opponent,
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