Official opponent's report on the thesis doctorate Hamza Benzerrouk
«Modern Approaches in Nonlinear Filtering Theory Applied to Original Problems of Aerospace Integrated Navigation Systems with non-Gaussian noises»

One of the major problems in determining a position and an orientation of the autonomous vehicles (aerial or ground) is a correct integration of signals from sensors. Of course, the complexity of this problem increases with the number of sensors and with increasing noise pollution of different signal interference. The solution of this problem is performed by means of a suitable filter the signals. In the present work, an analysis and comparison of the modern nonlinear robust algorithms of signal filtration with non-Gaussian noise is considered.

Main part of the thesis has a following structure. General principles of filtration theory in application to signal from multiple sensors are considered in section 2.1. Section 2.2 is devoted to detail description of different simplest linear and non-linear filter algorithms. In particular, author considers here:

- Extended Kalman filter algorithm
- Information filter and non-linear information filters
- Sigma points Kalman filters
- The 2nd order divided difference filter
- Particle filter

In the next section a modern non-linear filter algorithms are considered

- Cubature Kalman filter algorithm
- Gauss Hermite Kalman filter
- Gauss Hermite qudarature Kalman filter

Section 2.4 contains adaptive fading non-linear filter algorithms. In this section author consider the following filters:

- Adaptive fading extended Kalman filter algorithm
- Adaptive fading sigma points Kalman filters
- Adaptive fading divided difference filter
- Adaptive fading cubature Kalman filter

In the present work one can see that procedures adaptive fading filter algorithms converge faster standard versions of these filter algorithms. Author also offers an improvement of adaptive fading sigma points Kalman filters; this improvement leads to best accuracy and time of convergence.

In sections 2.5, 2.6 author considers Gaussian mixture cubature Kalman filter and that this filter is robust with respect to non-Gaussian noise. It is observed that the proposed robust Gaussian Mixture filters provide much better estimation with better accuracy comparing with other methods and applications founded in literature. Далее показано, что velocity estimation is more accurate with new formulated algorithms proposed in this work; unscented Kalman filter and cubature Kalman filter are better estimators than central difference Kalman filter and extended Kalman filter based on Gaussian mixture. It is then possible to observe that cubature Kalman filter outperforms unscented Kalman filter, central difference Kalman filter and extended Kalman filter comparing to ACRLB. Author show also that for classic nonlinear filters, extended Kalman filter and central difference Kalman filter presented comparative results and in major cases of velocity and attitude angle estimation, both diverge. At the opposite, unscented Kalman filter and cubature Kalman filter with other comparative results different from velocity to attitude angles estimation, show decreasing in estimation error and diverge only in attitude state estimation. By analyzing robust extended Kalman filter, unscented Kalman filter, central

difference Kalman filter and cubature Kalman filter, it is possible to distinguish the superiority of cubature Kalman filter during velocity state estimation and pitch angle estimation. For roll and yaw angles state estimation, robust CDKF and robust extended Kalman filter outperform unscented Kalman filter and cubature Kalman filter.

Section 2.7 is devoted to applications of considered filters for description of unmanned aerial vehicle, surface robotics vehicle and pedestrians positions. For multiple sensors fusion problems such as for unmanned aerial vehicle, robot navigation and pedestrian navigation problems, a decentralized data fusion based on Cubature Information Filter has been selected and is proposed as the best solution.

The author of thesis works done on analysis and comparison of different algorithms for nonlinear filtering, and he offers their improved versions of these algorithms. All considered algorithms are tested in practice including analysis of positions for unmanned aerial vehicle, surface robotics vehicle and pedestrians. The results of the thesis were presented at international conferences and published in more than 30 printed papers, including 6 publications from the list of VAK. Part of the results of the work already patented, another application for a patent is pending.

I think that the author of the thesis deserves the award of a degree of doctor of philosophy in mathematics.

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