Sigma-Point Kalman Filtering for State Estimation

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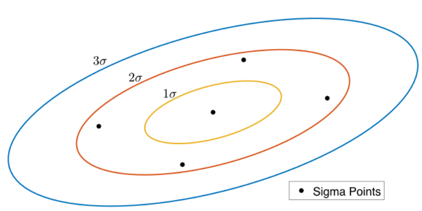
In order to gather environmental data in aquatic environments, the DISAL has developed an autonomous underwater robot. To autonomously navigate, the AUV should compute its state (position and orientation) accurately. This is currently done by using an *Extended Kalman filter*, a recursive Bayesian estimator. It approximates the dynamics of the AUV by a first order Taylor approximation. Thence an analytic computation of the Jacobians of the dynamics model are required. In a near future, new sensors will be added to the system to counter the absence of GPS measurements while navigating underwater. This means that the measurement models will change, but the EKF forces us to compute the analytic Jacobian each time a model changes, making the process tedious and error-prone.

A solution explored is to replace the existing EFK by one of the *Sigma point Kalman filters*. The SPKF do not only have the advantages of being Jacobian-free, but they also approximate the state more accurately than the EKF.

The sigma-points are a carefully chosen set of weighted points, used to approximate a distribution. They are chosen in such a way that the first and second order moment of the distribution are completely captured.

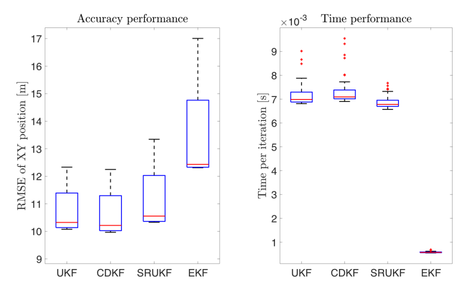


Example of sigma-point for a 2D Gaussian

The SPKF algorithm present an interesting feature: the set of sigma-point is not unique, i.e. it is possible to select a set of sigma-point that minimizes the estimation error and thus give higher accuracy.

The different algorithms belonging to the SPKF family have similar performance. They all have a complexity of $O(L^3 + LM^2 + L^2M)$, where L and M are the dimension of the state and measurements respectively. Compared to the EKF whose complexity is: $O(L^2 + M^{2.4})$, the SPKF has a higher cost.

The performance of each algorithm, applied to the state estimation of an autonomous surface vehicle is done by simulating the state estimator in Matlab and using different prerecorded data of the real system. The results obtained (shown below) are for four different data-set where, in two of them, the ASV goes in a straight line and in the other it performs sharp turns.



Performance in term of accuracy and computational complexity for the state estimation of an ASV. The experiments where made without GPS update to be in the same condition as the AUV.

	EKF	UKF	CDKF	SR-UKF
Mean of RMSE	13.5460	10.7642	10.6614	11.1957
Improvement	-	20.5%	21.3%	17.3%

Numerical results for the accuracy

We have improvements in term of accuracy, around 20%, but in term of computational complexity, the SPKF are approximately 10 times slower. In fact, with the current implementation, it is impossible to use the SPKF for system running faster than 140Hz, which makes its use impossible for the AUV. A solution would be to use a modular state estimator, where two state estimators runs a different frequency. This would reduce the state dimension and thus the time complexity.