Multiple target Tracking with PHD Filters

**Objective** Estimate an unknown, time varying number of targets and their states from noisy observations available at discrete intervals of time. Software currently under development.

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**General problems** Tracking multiple manoeuvring targets in a surveilled region involves at each time step the joint estimation of the number of targets as well as their state vectors. Clutter, uncertainties in the dynamic of the maneuvers, in data association and in target detection make this process very difficult. The intrinsic problem of multiple-target tracking is the impossibility to known with certitude the correct association between the measurements and the targets that have generated them.

**Traditional approaches** An alternative solution to traditional approaches like Multiple Hypotheses tracking (MHT), Joint Probabilistic Data Association Filter (JPDAF) or (PMHT) Probabilistic MHT, is based on the Random Finite Set (RFS) formulation in which the collection of individual targets is treated as a set-valued state and the collection of observations as a set-valued observation. This approach, joined with Mahler's finite set statistics (FISST), has lead to the development of an effective class of multiple-target filters such as the Probability Hypothesis Density (PHD) filters.

You can find here some example of the application of two approximations of the PHD recursion: a Sequential Monte Carlo PHD filter (SMC-PHD) and a Gaussian Mixture PHD filter (GM-PHD) to a realistic naval and aerial scenario.

**PHD Filters**

The Probability Hypothesis Density (PHD) filter is a multiple-target filter for recursively estimating the number and the state of a set of targets given a set of observations. It is able to operate in environments with false alarms and misdetections and it works by propagating in time the intensity of the targets RFS instead of the full multi-target posterior density. In literature, various implementations have been proposed and their performance compared using different levels of clutter and model uncertainty. The generic sequential Monte Carlo implementation (SMC-PHD) filter, proposed by Vo et al. in [4], generally suffers of an high computational cost as it requires a large number of particles and relies on clustering techniques to provide state estimates. The unreliability of estimates due to inaccuracy introduced by the clustering step and the computational complexity constitute its main drawbacks. To alleviate these problem a closed form solution to the PHD filter recursion, called Gaussian Mixture PHD (GM-PHD), has been proposed by Vo and Ma in [7]. This approach does not require clustering procedures but, since it makes use of the Kalman filter equations, it is restricted to linear-Gaussian target dynamic. When targets show a mildly non-linear dynamic it is generally possible to rely on extensions for the GM-PHD filter using the Extended Kalman filter (EK-PHD) or the Unscented Kalman filter.
(UK-PHD) or to use the Gaussian Particle Implementations of the PHD filter.

**Example I**

An unknown, varying number of targets move along the line segment \([-100,100]\). The state of the targets consist of position and velocity; only the position is observed. Targets may appear or disappear at any time during and are subjected to random accelerations.

The system evolution is partially observed by the following observation model:

\[ y_m = [1 \ 0] \begin{bmatrix} x_n \\ \frac{dx_n}{dt} \end{bmatrix} + \nu \]

Clutter intensity: 0, Probability of detection: 0.9

The output of the SMC-PHD filter reported below is the particle approximation of the intensity function:

The approximated PHD function is obtained by summing the weights of the particles at each time step:
Clutter intensity: Poisson process with average of 5, Probability of detection: 0.9

Example II
This section considers the application of the PHD filter to an aerial and naval multiple-target tracking scenario. The purpose is to track an unknown, time-varying number of aircrafts and ships in a region of surveillance determined by the characteristics and location of the radar mounted on a naval platform. The target evolution is modeled using a Constant Velocity model perturbed by random accelerations. The radar is mounted on a ship located at the origin of the reference system and considered not moving. It completes a 360 degrees scan in a fixed amount of time $T$ and collects measurements of targets that are within a certain range and whose elevation angle is between a maximal and a minimal value. The radar is unable to localize targets that are too close (within a blind distance of 300 mt.); the measurements collected are affected by a Gaussian, zero centred random noises with known variances.

The clutter model takes into account the geometry of the surveilled region and, to a lesser degree, its physical properties. It is modelled as the superposition of two Poisson point processes with different intensities. The first is used to model the false alarms generated by the reflection of the electromagnetic beam over the surface of the sea and the second is used to model the spurious measurements generated by termic and atmospheric noises in the surveilled region of the sky.
SMCPHD Filter with K-Means Clustering:

Video example of GMPHD-Filtering:

In this example the GMPHD Filter is used to filter the position of 99 naval targets moving in the surveillance zone. During each time step 50 false alarms are registered (clutter).