

Integrated GMTI Radar and Report Tracking for Ground Surveillance

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Abstract – The fusion of information gathered from multiple sources is essential to build a comprehensive situation picture for ground surveillance. In this paper, an approach which performs data correlation and fusion for ground moving target indicator (GMTI) radar data and SALUTE reports is described. GMTI data are simulated based on the ground truth of a military exercise and processed by a GMTI group tracker employing a Cardinalized Probability Hypothesis Density (CPHD) Filter. Multi source fusion is performed by combining the GMTI tracker and report tracker using our data fusion architecture. The scenario used in the experiment is tracking of closely spaced ground targets by GMTI, supplemented with some collected SALUTE reports. The challenges include tracking ground targets moving across foliage and tactical movement (start-stop mode). Using the designed test scenarios, this paper looks into different aspects of benefits by performing cross fusion with GMTI data and SALUTE reports.

Keywords: Ground Target Tracking, Group Tracking, Cardinalized Probability Hypothesis Density Filter, Track Correlation, Track-to-track fusion.

1 Introduction

Fusing and tracking of ground targets from multiple sources in wide area ground surveillance is a challenging problem. The main difficulty is the fusion of information from different update rates, out-of-sequence reports, and fragmented visibility. The Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE) developed a GMTI tracking algorithm which is used in a German exploitation station in an ongoing international technology program. It has been evaluated in real and simulated exercise with a variety of different GMTI sensors. The GMTI tracking algorithm is capable of tracking single vehicle and convoys. On the other hand, Singapore's Defence Science Organisation (DSO) developed a report tracking algorithm. A typical report contains information such as size, action, location, unit, time and

equipment (SALUTE). Unlike GMTI data which have a high update rate (of the order of ten seconds per wide area scan) but with no target classification, SALUTE reports have a low update rate sometimes in terms of several minutes or even hours. This is due to the deployment and revisit of the limited sensor resources. Both Fraunhofer FKIE and DSO decided to combine GMTI tracking with report tracking by exploiting complimentary combination and attribute refinement.

This paper presents a data fusion architecture for multi-source ground target tracking. It combines GMTI tracks and report tracks so as to derive the benefits of cross fusion. For this experiment, reports and ground truth of a military exercise over a period of four days were collected. The scenario was analyzed to identify ground moving targets. A GMTI simulator is employed to generate the GMTI radar plots based on the moving targets in the ground truth of the exercise. Next, the GMTI plots are processed by a GMTI group tracker which is able to perform convoy or group tracking by clustering on the track level. Report tracking is then performed based on the SALUTE reports. Finally, tracks resulted from the GMTI group tracker and report tracker are passed to the track-to-track correlation framework for cross fusion.

This paper is organized as follows: Section 2 describes the data fusion architecture to integrate the GMTI tracks and the report tracks, with an explanation on the report tracker and track fusion. Section 3 describes the GMTI simulation framework used to generate the GMTI plots and tracks. Section 4 gives an explanation on the CPHD-GMTI tracker. Lastly, testing and experimental results on selected, operationally relevant situations are presented in Section 5.

2 Data Fusion Architecture

In this collaboration, DSO National Laboratories contributed the report tracker and the track-to-track correlation framework for combining GMTI group tracks

and report tracks [1,2]. Fraunhofer FKIE provided the GMTI simulation framework for the radar plots generation, as well as the GMTI tracker (with grouping) for tracking vehicles moving in convoys. A scheme to combine these components provided by both parties is investigated and implemented as shown in Figure 1.

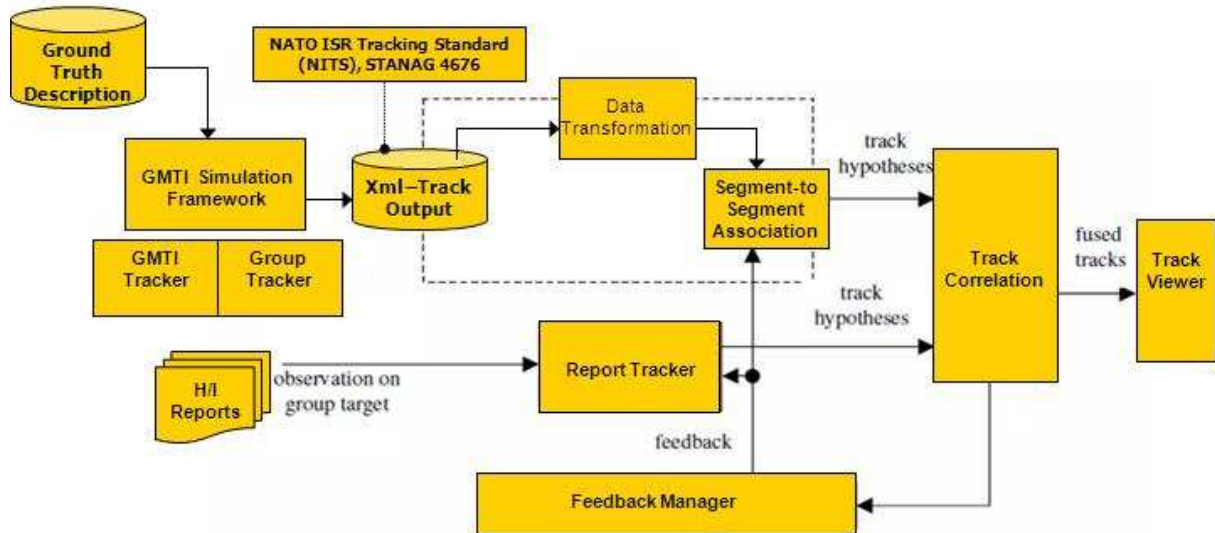


Figure 1: Data Fusion Architecture for combining GMTI radar plots and SALUTE reports.

2.1 Data Fusion Strategy

The data fusion strategy to combine these two different data sources is briefly explained as follow:

- First, the GMTI tracker tentatively extracts tracks based on the radar plots and assigns weights to each track based on the CPHD filter algorithm (see Section 4). Only tracks with weight above a certain threshold are considered as candidate tracks.
- The GMTI group tracking module merges individual tentative tracks that are close together and forms a group track. The total weight of the group track is given by the sum of individual weight which provides an estimate of the target number (group size).
- The group tracker produces an output file for each GMTI scan. The output file contains a list of “confirmed group tracks” for that particular scan. At the end of a given period of time, the tracker has generated a list of output files in XML format. The format is based on the drafted NATO ISR Tracking Standard (NITS), STANAG 4676.
- The data transformation module reads the GMTI data files and performs the necessary data transformations.

- The segment-to-segment module examines any “broken tracks” and tries to links them up.
- The Report tracker looks up the report file that contains a set of observations on group targets. The Report tracker performs report tracking, and

produces the report tracks.

- During the report tracking process, the reports are tentatively correlated with GMTI tracks; the correlation information of high confidence is feed back to both the report tracker module, and the GMTI segment-to-segment association module to improve the performance of each other.
- Eventually, the engine confirms the correlation of report tracks and GMTI tracks via a multiple hypothesis testing process and the final results are output.

2.2 Report Tracker

The role for the report tracker is to form tracks from SALUTE reports which have low update rate. The key algorithms used for the report tracking is Multiple Hypothesis Tracking (MHT). Here, a hypothesis is an assumed assignment of reports to tracks; it is usually represented by a set of disjoint tracks, with each report belonging to one and only one track in a hypothesis. Each hypothesis contains a probability indicating the extent that the hypothesis is true. The probabilities are computed based on the matching degree between reports and tracks, in terms of entity types, quantities, as well as time and space consistency, etc.

For report-to-report association, a non-traditional Bayesian inference algorithm (i.e., Bayesian sub-net) is employed to compute the posterior probability of association/correlation between reports [1]. The Bayesian subnets model probabilistically the relations between observed attributes, target moving status, as well as time-space consistencies. Uncertainty in equipment type is allowed and modeled by Dempster-Shafer theory.

2.3 Track Correlation

The track correlation module correlates report tracks from the report tracker and the GMTI tracks from the segment-to-segment association module to identify whether the tracks correspond to common targets. If so, the information in the tracks can be combined, and attribute refinement and supplementary combination of attributes can be performed. Because the observations are sparse and the time stamps of different observations are not synchronized, the correlation problem cannot be solved solely by comparing the last observation in the tracks. When all the observations from the history of two tracks are consistent based on the belief of association, the tracks are correlated [1].

3 GMTI Simulation Framework

Details of the simulation framework, including sensor parametrization, and generation of GMTI radar plots are described in [3]. For the present study we selected suitable test cases with convoy movements from the given military exercise. Since the time grid of the original records of the exercise was of the order of five minutes, the ground truth for the sensor simulation had to be generated on a much finer time grid of the order of seconds by a linear interpolation between subsequent time frames. This ground truth simulation, combined with a GMTI platform simulation, serves as input for a GMTI sensor model (Figure 2). The sensor model generates scan-wise measurements of all visible ground targets in azimuth, range, and range rate. It simulates effects of measurements noise, limited sensor resolution, false alarms, and missed detections, e.g., for “low Doppler” targets. In particular, only moving targets are detectable by the GMTI sensor. A stand-off GMTI platform is assumed in a distance of 100km with a wide area scan interval of 20 seconds.

The generated GMTI radar plots are scan-wise processed by the tracker.

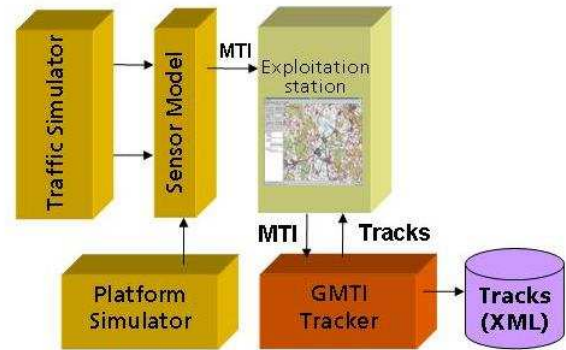


Figure 2: GMTI Simulation Framework for generating GMTI plots and tracks.

4 CPHD Tracker for Ground Targets

4.1 GM-CPHD filter

The Cardinalized Probability Hypothesis Density (CPHD) filter is a Bayesian filter algorithm for tracking multiple targets in clutter.[4,5,6] In particular the Gaussian mixture variant [7] (GM-CPHD) for linear, Gaussian systems is efficient and feasible, and leads to stable target number estimates. It has been applied to the problem of ground moving target tracking in [8]. GM-CPHD has strong similarities to standard Multi Hypothesis Tracking (MHT) [9,10], as the estimated quantity – the Probability Hypothesis Density (PHD) – is described by a weighted sum over Gaussian components. In contrast to MHT, the sum of the weights directly gives the estimated target number. In the single target limit, the PHD becomes a probability density and GM-CPHD can be shown [8] to be equivalent to single target MHT, including a sequential likelihood test for track extraction [11,12]. For multiple targets, GM-CPHD is an approximation to the full-blown multi-target filter, as it does not estimate the full, high-dimensional multi-target probability density, but only the PHD which is a measure of the number of targets in a given region of the (single-target) state space. For a numerical comparison between GM-CPHD and MHT for ground target applications see [13].

In scenarios with several disperse targets or target groups, it is essential to perform clustering before CPHD tracking, not only because of performance reasons but also because of an artificial, “unphysical” correlation effect in CPHD between targets which are arbitrarily far apart [14]. As such situations occur in the present paper, we apply a “localized” GM-CPHD filter as described in [14].

4.2 Track extraction

Track extraction is done by introducing a “test” component with a certain, small weight corresponding to the expected rate of new targets. When receiving a series of correlated measurements, the weight of the test component increases. If the weight exceeds a certain threshold, the component is called “confirmed track”. When the track weight falls below another threshold, a “track drop” is declared. The susceptibility of the filter to vanishing targets can be enhanced by introducing a “death rate”, corresponding to the expected probability that a target vanishes in a given period of time. Details are given in [8].

4.3 Group tracking

Different components which are close, defined by the Mahalanobis norm, can be merged into a single group track. In that case the track’s kinematic estimate defines the center of mass of the group (e.g., the convoy) and the sum of the weights defines the target number. The precision of the estimates are given by the estimated covariance of the kinematic state and by the cardinality distribution, respectively.

5 Scenario and Results

The scenario in this experiment is a military operation of REDLAND Armed Forces (RAF) and BLUELAND Armed Forces (BAF).

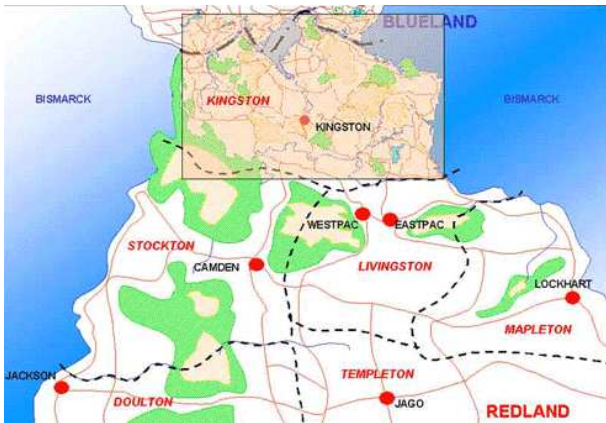
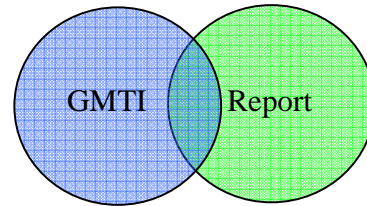


Figure 3: Geographical boundary between BLUELAND and REDLAND.

The REDLAND and BLUELAND are situated at the south and at the north of this scenario map respectively. The geographical boundary between the BAF and RAF is shown in Figure 3. Due to rising tension between the REDLAND and BLUELAND, the RAF is establishing a defensive line at Kingston state, which is in Northern REDLAND. The selected test plans are a subset of this military scenario over a period of four days. The focus is

to track the ground targets of a division that tasked to move from Livingston state and to deploy at eastern part of the Kingston state.

For each selected test, the GMTI plots were simulated using a finer time grid instead of the discrete time steps used in the ground truth. This ground truth database was used in the GMTI simulation framework to produce the GMTI tracks.



GMTI radar performs wide area scan and tracks all ground moving targets, while SALUTE report collected from the ground, monitor only targets close to a specific location. On the other hand, the latter is capable of observing both moving and stationary targets. By combining these two sources of track data, we extend the coverage and improve the ground situation picture. Besides extending the coverage, as sketched in the above drawing, there is overlapping of tracks data covered by GMTI radar and SALUTE reports. This common information can be correlated and the resultant can be used to improve existing tracking results. Although there is a limited number of possible track correlations, it may still be interesting to look at the how well the system has performs on the correlated tracks data.

The overall system performance is evaluated using a selected dataset of three hours where reports were available and GMTI plots from several moving target were present. In this evaluation, two criteria are used: 1) association correctness and 2) precision. Association correctness measures the accuracy of report-to-report association, while, precision measures the accuracy of the tracks found at a particular time point. The index to compute the association correctness is:

$$\text{Correct Rate} = m1/M$$

where $m1$ is the number of reports correctly associated and M is the total number of reports. Running the test without the feedback of GMTI data, the report tracker correctly associated 49 reports out of 60 reports with a correct rate of 0.817. Subsequently, the test is repeated with the feedback of GMTI data, the number of correct associated reports become 51 with a correct rate of 0.850.

For precision, the calculation is given by:

$$\text{Precision} = \# \text{ correct tracks} / \# \text{ detected tracks}$$

Without the GMTI data, the system formed a total of 49 tracks, of which 44 tracks are correct. The precision value is 0.898. Using the GMTI track data, the number of tracks formed is 47 and the number of correct tracks remains as 44. The precision value is 0.936. It can be seen that the system performance is now better after introducing GMTI track data into the report tracker. The size of the improvement is limited due to the small number of possible tracks correlations for the given scenarios.

In the following, a few test cases are discussed in some detail for a qualitative analysis. In the first test case, a convoy of four vehicles moves away from a deployed position and travels continuously for one hour without stopping. The GMTI tracker correctly tracks the vehicles, clusters them as a convoy and produces one continuous group track. Within the same time period, there is a list of SALUTE reports collected, of which only two reports correspond to the same convoy. Purely using the report tracker, the tracker wrongly associates the two reports with six other reports which belong to another unit as shown in Fig 4.

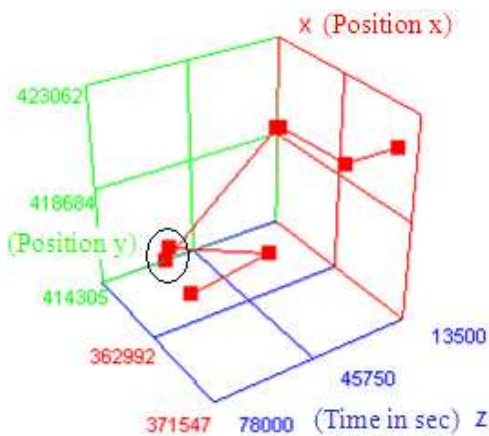


Figure 4: Two reports of the target wrongly associated with another six reports of a nearby unit.

The experiment was repeated using the data fusion architecture with GMTI and report tracker. The output from the track-to-track correlation process (see Fig 5) shows the GMTI track combines with the two reports. The data fusion architecture successfully correlates the GMTI track with the report track, and hence correct report tracking error. With the exclusion of two reports, the remaining six reports form a separate track.

From the above experiment, the proposed scheme to combine a GMTI tracker and a report tracker is demonstrated. Once the two tracks are correlated, the GMTI track can refine and update the location of the

report track. On the other hand, the report track complements the GMTI track with target classification.

In the second test case, an Armored Personnel Carrier (APC) moves from point A to point B. Along the route, the APC passes through a small plantation. It takes about 15 minutes to travel through the foliage area. Due to the blackout, the GMTI tracker is unable to track the target continuously. It produces two separate GMTI tracks as shown in Fig 6.

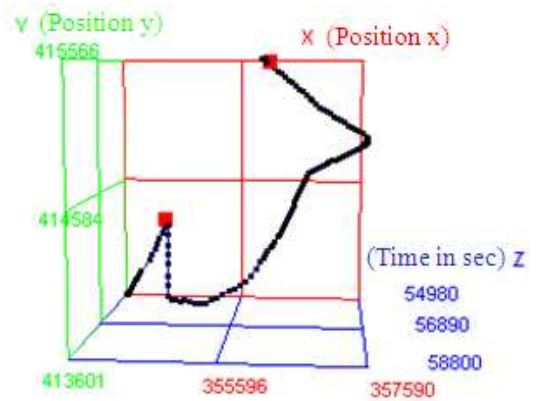


Figure 5: The GMTI track successfully combined with corresponding SALUTE reports.

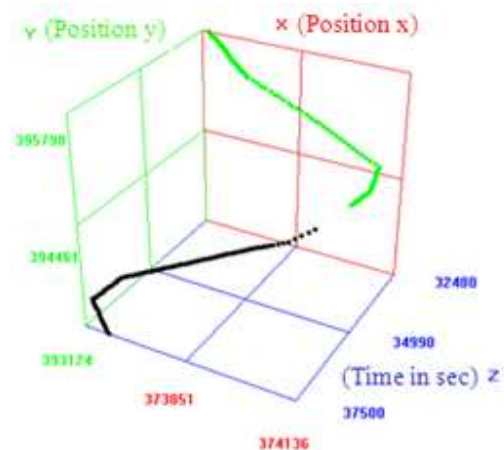


Figure 6: Two GMTI broken tracks due to foliage zone

Using the data fusion architecture, it can be seen from Fig 7 that the two GMTI segments can be linked up as a single track. The segment-to-segment association helps to connect the broken GMTI tracks referring to the same target and improves the track continuity of the GMTI.

The third test case concerns a convoy of 10 medium trucks moving in a start-stop-start mode. The vehicles move for 20 minutes, rest for 20 minutes and moves again for another 15 minutes. As such, the GMTI tracker produces

two GMTI tracks. Two reports are observed, one recorded before the convoy rest and one taken when the convoy re-commerce its movement after the break. The output track from the GMTI tracker shows two separated tracks.

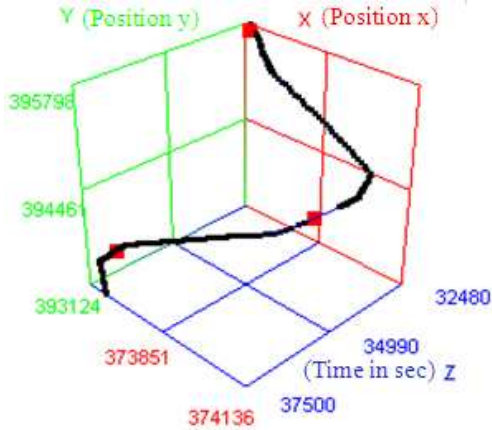


Figure 7: Segment-to-Segment association module linked up the two broken GMTI tracks.

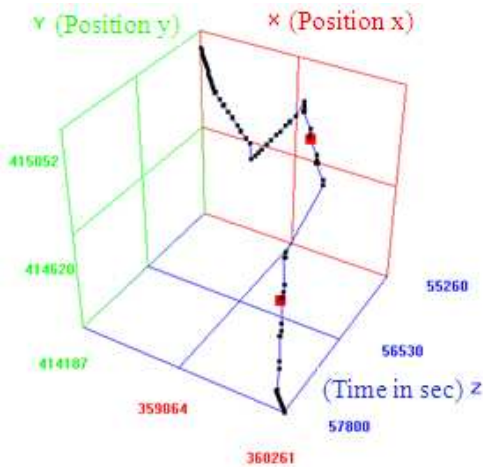


Figure 8: Two GMTI broken tracks are linked up and associated with two reports. This is an improvement based on feedback from high quality report tracks.

However, by feeding the GMTI tracks and the collected reports to the data fusion architecture, as shown in Fig 8, the algorithms associate the track with the two reports with the GMTI tracks and link up the two GMTI segments. This is a result due to feedback from high quality report track. The report tracker associates the two reports with a high score, and this piece of information is forwarded to the segment-to-segment association via the feedback mechanism.

6 Summary

In this paper, an approach to the information fusion from two very different sources (GMTI radar and SALUTE report) has been presented. Through the integration of a GMTI simulator and a GMTI group tracker into a multi source fusion architecture, it demonstrates the system capabilities in combining GMTI tracks and report tracks. Using a realistic military scenario, this paper also illustrates the benefits of cross fusion whereby the GMTI tracks help to improve the quality of report track with a fast location update, and the report tracks complement the GMTI tracks with target classification. Furthermore, the study in this paper shows that the GMTI track continuity can be improved via the segment-to-segment association and/or feedback from the report track.

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References

- [1] X. Xiao, H. B. Lee, W. C. Chin, G. W. Ng, K. Y. How, "Combination of Multi-source Information to Ground Target Group Tracking", in Proc. Multisensor, multisource information fusion. Conference, Orlando FL , USA, 2005, vol. 5813, pp. 162-172.
- [2] X. Zhang, H. B. Lee, G. W. Ng, K. Y. How, H. K. Chan, W. C. Chin, "Novel Fusion Algorithms For Multiple Sensor Systems", in Proc. Ninth Int. Conf. on Information Fusion, Florence, Italy, July 2006.
- [3] G. Schüller and M. Mertens, „A Simulation Framework for Testing GMTI Trackers“, submitted to 13th Int. Conf on Information Fusion, Edinburgh, UK, July 2010.
- [4] R. Mahler, PHD filters of higher order in target number, IEEE Trans. Aerospace and Electronic Systems, vol. 43 (4), 1523-1543, Oct. 2007.
- [5] R. Mahler, "Statistical Multisource-Multitarget Information Fusion", Artech House, 2007.
- [6] O. Erdic, P. Willett, and Y. Bar-Shalom, "The Bin-Occupancy Filter and Its Connection to the PHD Filters", IEEE Trans. Signal Processing, vol. 57 (11), 4232 - 4246, Nov. 2009.
- [7] B.-T. Vo, B.-N. Vo, and A. Cantoni, "Analytic implementations of the cardinalized probability hypothesis

density filter,” IEEE Trans. Signal Processing, vol. 55 (7), 3553 – 3567, July 2007.

[8] M. Ulmke, O. Erdinc, and P. Willett, “Gaussian mixture cardinalized PHD filter for ground moving target tracking,” in *Proc. Tenth Int. Conf. on Information Fusion*, (Quebec, CA), July 2007

[9] D. B. Reid, “An Algorithm for Tracking Multiple Targets”, IEEE Trans. on Automatic Control, Vol. Ac-24, No.6, pp. 843-854, Dec 1979.

[10] S. S. Blackman. “Multiple-Target Tracking with Radar Applications”, Artech House, Chapter 10, The Bayesian Probabilistic Approach, Chapter 14.3 An Implementation Method for Multiple Hypothesis Tracking, 1986.

[11] G. van Keuk, “Sequential track extraction,” IEEE Trans. Aerospace and Electronic Systems, vol. 34, pp. 1135–1148, 1998.

[12] A. Wald, *Sequential Analysis*, John Wiley, New York, 1947.

[13] D. Svensson, J. Wintenby, and L. Svensson, Performance evaluation of MHT and GM-CPHD in a ground target tracking scenario, 12th Int. Conf. on Information Fusion, Seattle, USA, July 2009.

[14] D. Fränken, M. Schmidt, and M. Ulmke, "Spooky Action at a Distance" in the Cardinalized Probability Hypothesis Density Filter, IEEE Trans. Aerospace and Electronic Systems, vol. 45 (4), 1657, Oct. 2009.