

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188		
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1. REPORT DATE (DD-MM-YYYY) 15-12-2010		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 1-Oct-2006 - 30-Sep-2010	
4. TITLE AND SUBTITLE Network Level Association and Fusion of Kinematic and Attribute Information			5a. CONTRACT NUMBER W911NF-06-1-0467		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER 611102		
6. AUTHORS Yaakov Bar-Shalom			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of Connecticut - Storrs Office for Sponsored Programs University of Connecticut Storrs, CT 06269 -1133			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSOR/MONITOR'S ACRONYM(S) ARO		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 51018-CS.1		
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT This work investigates the various criteria for track-to-track association/fusion (T2TA/F): likelihood ratios and distance criteria. Procedures to obtain the quantities needed by the LR criterion from the limited information available from the real world communication networks are developed. Algorithms for T2TA/F with heterogeneous sensors and investigation of several assignment algorithms for the					
15. SUBJECT TERMS Track-to-track association/fusion (T2TA/F), Kinematic and Attribute Information					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Yaakov Bar-Shalom
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 860-486-4823

Report Title

Network Level Association and Fusion of Kinematic and Attribute Information

ABSTRACT

This work investigates the various criteria for track-to-track association/fusion (T2TA/F): likelihood ratios and distance criteria. Procedures to obtain the quantities needed by the LR criterion from the limited information available from the real world communication networks are developed.

Algorithms for T2TA/F with heterogeneous sensors and investigation of several assignment algorithms for the T2TA problem are carried out.

Procedures for simultaneous handling of continuous valued (kinematic and feature) states and discrete valued ones (attribute/classification) for an integrated approach to the Track Association and Fusion problem are presented.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

- 278.(J139) A. Sinha, T. Kirubarajan and Y. Bar-Shalom, ``Application of the Kalman-Levy Filter for Tracking Maneuvering Targets", {\bf IEEE Trans.\ Aerosp.\ Electronic Systems}, 43(3):1099--1107, July 2007.
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Number of Papers published in peer-reviewed journals: 35.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

314. V. Ravindra, Y. Bar-Shalom and S. Gottesman, "Aim Identification with a Minimal Parameter Set", {\bf Proc.\ 2006 IEEE/AIAA Aerospace Conf.}, Big Sky, MT, March 2007.
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367. S. Schoenecker, P. K. Willett and Y. Bar-Shalom, "Maximum Likelihood Probabilistic Data Association Tracker Applied to Bistatic Sonar Data Sets", {\bf Proc.\ SPIE Conf.\ Signal and Data Processing of Small Targets}, \#7698-19, Orlando, FL, April 2010.
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370. D. F. Crouse, Y. Bar-Shalom, P. K. Willett and L. Svensson, "More Ways to Track Closely-Spaced Targets Than You Wanted To Know or Tips For Not Pissing Off the Radar Operator So Much That He Turns Off the Track Display", {\bf Proc.\ ONR-GTRI Workshop on Tracking}, Santa Barbara, CA, May 2010.
371. S. Zhang and Y. Bar-Shalom, "Survey of OOSM problems: Updates, Removals and Biases", {\bf Proc.\ ONR-GTRI Workshop on Tracking}, Santa Barbara, CA, May 2010.
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373. X. Tian and Y. Bar-Shalom, "On Algorithms for Asynchronous Track-to-Track Fusion", {\bf Proc.\ 13th Intn'l Conf.\ on Information Fusion}, Edinburgh, Scotland, July 2010.
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Range Rate Measurements", {\bf Proc.\ 13th Intn'l Conf.\ on Information Fusion}, Edinburgh, Scotland, July 2010.

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381. R. Tharmarasa, T. Kirubarajan, N. Nandakumaran and Y. Bar-Shalom, ``Profile-Free Launch Point Estimation for Ballistic Targets Using Passive Sensors", {\bf Proc.\ 2011 IEEE/AIAA Aerospace Conf.}, Big Sky, MT, March 2011.

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 51

(d) Manuscripts

Number of Manuscripts:

Patents Submitted

Patents Awarded

Awards

2008 IEEE Dennis J. Picard Medal for Radar Technologies and Applications

2010 Faculty Excellence in Research Award from the UConn Alumni Association

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Vishal Ravindra	1.00
Ting Yuan	1.00
Javier Areta	1.00
Xin Tian	0.50
Shua Zhang	0.50
FTE Equivalent:	4.00
Total Number:	5

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Yaakov Bar-Shalom	0.25	No
FTE Equivalent:	0.25	
Total Number:	1	

Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

<u>NAME</u>
Total Number:

Names of personnel receiving PHDs

<u>NAME</u>
Wayne Blanding
Atef Isaac
Javier Areta
Ozgur Erdinc
Vishal C. Ravindra
Xin Tian
Total Number:

6

Names of other research staff

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Inventions (DD882)

FINAL REPORT

1 Oct. 2007 – 30 Sep. 2008

Grant ARO W911NF-06-1-0467
Proposal 51018-CI

Network Level Association and Fusion of Kinematic and Attribute Information

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December 15, 2010

1 Foreword

The track-to-track association/fusion (T2TA/F) problem has been considered until recently in the literature only for pairwise associations. In view of the extensive recent interest in multisensor data fusion, the need to associate/fuse simultaneously multiple tracks has arisen. This is due primarily to bandwidth constraints in real systems, where it is not feasible to transmit detailed measurement information to a fusion center but, in many cases, only tracks based on data obtained by local sensors — local tracks. The performance of the T2TA and subsequent fusion has been shown recently to be remarkably close (within 10% in MSE) to that of the fully centralized architecture where all the measurements are sent to the fusion center (FC). These considerations motivate the investigation of the criteria as well as the optimization algorithms for the general T2TA/F problem. As it has been known in the literature, tracks of the same target obtained from independent sensors are still dependent due to the common process noise. A comprehensive solution of the T2TA problem is a prerequisite for successful fusion. The solution to the T2TA problem consists of two steps: a proper criterion function and an efficient algorithm to optimize it. The present work investigates the possible criteria for the T2TA problem from multiple and possibly heterogeneous sources, which form the basis for the cost function used in a multidimensional assignment algorithm that can solve a realistic large scale problem where many sensors track many targets. Since the T2TA procedures discussed in the literature are for tracks that are characterized by (continuous) kinematic states, we develop techniques that can handle simultaneously continuous as well as discrete — attribute/classification — states. Since in many real systems the information necessary for the association criterion is not available in full, procedures to obtain the missing information will also be considered. Such information is the track covariances, the crosscovariances and, in some situations, even the sensor measurement noise covariances are not known. The next part of the investigation deals with the various algorithms to optimize the association criterion. The investigation of the various assignment algorithms is carried out in the context of a realistic problem. The T2TA/F problem for heterogeneous sensors considers the situation where the state vectors of the local tracks are different as in the case of an active and a passive sensor. A framework is developed for such situations to carry out both the association as well as the fusion with maximum information benefit.

2 Statement of the Problems Studied

The following problems were the principal objective of our study:

1. Investigation of criteria for Network Level Track-to-Track Association: the Normalized Distance Squared and the Likelihood Ratio.
2. Development of procedures to obtain the quantities needed by the Likelihood Ratio criterion from the limited information available from the real world communication networks.
3. Development of algorithms for Track-to-Track Association and Fusion with Heterogeneous Sensors and investigation of several Assignment Algorithms for the Track-to-Track Association Problem.
4. Development of procedures for simultaneous handling of continuous valued (kinematic and feature) states and discrete valued ones (attribute/classification) for an integrated approach to the Track Association and Fusion problem.

3 Summary of the Most Important Results

The items below refer to the list of publications detailed in the Bibliography (Section 5). They provide a concise description of most important result(s) in each paper. The full papers have been sent to the ARO program manager and they are also available from the author of this report upon request.

291. Solved the general problem of T2TA from N sensors.
292. Developed a measurement extractor for Multiple Unresolved Extended Objects.
308. Developed Radar Measurement Noise Variance Identification method and applied it to real data.
314. Showed how to design a passive sensor base missile warning system.

315. Developed an efficient search method for the ML-PDA method in the presence of thousands of local maxima.
- 316,322. Developed an algorithm for Robust Tracking with Very Long Range Radars.
317. Extended the MLPDA to Multiple Target Tracking.
318. Proved that the CRLB is finite even near ‘Zero Information’ Points.
319. Developed MCMC Methods for Tracking Two Closely Spaced Targets Using Monopulse Radar Channel Signals.
320. For Targets with Fluctuating SNR a Multisensor Track Termination algorithm was developed.
- 321,323. Investigated and justified the Need for enhanced Resolution for Detecting and Tracking Separating Objects.
324. Developed an efficient algorithm for Removal of Out-of-Sequence Measurements from Tracks which avoids the very costly recomputation of associations in a window for the MHT.
325. Extended the ML-PDA to a Multitarget environment.
326. Developed Offline and Real Time Methods for ML-PDA Track Validation.
327. Developed a Hierarchical Track Association and Fusion for a Networked Surveillance System.
- 328,335. Developed a new paradigm of tracking without a measurement extractor.
329. Developed a new algorithm for Track Association and Fusion with Heterogeneous Local Trackers.
330. Presented a Historical Perspective on Multitarget Tracking.
331. Showed how to track in presence of a wake.
- 332,334. Presented a Robust Tracking method for Very Long Range Radars.
333. Developed A Multiple Model Filter for Impact Point Prediction for the AMRDEC’s Area Protection System.
- 336: Comparison of the Assignment Costs for Multiple Sensor Track-to-Track Association — work done in collaboration with ARL (Lance Kaplan).
337. Developed a Sequential track-to-track fusion algorithm over a time window.
338. Showed that the Sequential Track Correlation Algorithm in a Multisensor Data Fusion System has to account for the correlation of state estimates in the time window.
- 339,347. Developed an algorithm to evaluate the Probability of Misassociation Between Neighboring Targets.
- 340,346. Showed the benefits of multistep lookahead for Surveillance by Multiple Cooperative UAVs in Adversarial Environments.
341. Presented two Counterintuitive Phenomena in Track-to-Track Fusion and Association.
342. Compared the new Sliding Window Test to Single Time Test for Track-to-Track Association.
343. Developed an algorithm for Multitarget Tracking in the Presence of Wakes.
344. Presented a new algorithm for Tracking of Spawning Targets with Multiple Finite Resolution Sensors.
345. Showed the benefits of Multisensor Track Management for Targets with Fluctuating SNR.
- 348,357. Developed, in cooperation with ARL, Feature-Aided Localization of Ground Vehicles Using Passive Acoustic Sensor Arrays.
- 349,361. Obtained the Exact Algorithms for Four T2TF Configurations: All You Wanted to Know but Were Afraid to Ask.
350. Developed a robust image tracker with Multiple Kernel Centers.
351. For sensor networks, developed a Sensor Bias Estimation algorithm in the Presence of Data Association Uncertainty.
352. Revisited the problem of Unbiased Kalman Filter Using Converted Measurements.
353. Designed an adaptive passive collision warning system for UAVs’.
354. Developed a new approach designated The Bin-Occupancy Filter for estimating target presence.
355. The performance of Tracking Move-Stop-Move Targets was shown to improve with the use of State-Dependent Transition Probabilities.
356. The use of Combined Hypotheses in T2T and M2T Association gives better results than using only the most likely hypothesis.
358. Surveyed The Probabilistic Data Association Filter and its application to Estimation in presence of measurement origin uncertainty.
359. Developed Advanced Track Handover Using Fusion for BMD.

- 360. Came up with A Low Complexity Sliding Window Kalman FIR Smoother for Discrete Time Models.
- 362,373. The problem of Optimal Algorithm for Asynchronous Track-to-Track Fusion was solved.
- 363. A No-Loss Covariance Intersection Algorithm for Track-to-Track Fusion was developed.
- 364. A Track Segment Association for Ground Moving Targets with Evasive Move-Stop-Move Maneuvers was developed to overcome the problem of broken tracks.
- 365,379. An accurate algorithm for Impact Point Prediction for Short-Range Thrusting Projectiles was developed for AMRDEC.
- 366,368. Extensive comparisons of various implementations of The JPDAF in Practical Systems were carried out.
- 367. The Maximum Likelihood Probabilistic Data Association Tracker was Applied to real Bistatic Sonar Data Sets.
- 369. An IMM Approach was developed for Very Short Term Load Forecasting and Confidence Interval Estimation.
- 370,380. A systematic approach to designing the MHT Track Display was developed.
- 371. A Survey of OOSM problems for Updates, Removals and Biases, was compiled.
- 372. The problem of Tracking with Multisensor OOSM Measurements with Residual biases was solved.
- 374. Developed an ML algorithm for 2D Location Estimation of Angle-Only Arrays Using targets of Opportunity.
- 375. Developed Track-Before-Detect Algorithms for Targets with Kinematic Constraints.
- 376. A substantially simpler expression for The Dynamic CRLB for Target Tracking in Clutter was obtained.
- 377. A Novel Filtering Approach for the General Contact Lens Problem with Range Rate Measurements was obtained.
- 378. The Optimal Removal algorithm of Out-of-Sequence Measurements From Tracks Using the IF-Equivalent Measurement was obtained.
- 381. A robust Profile-Free Launch Point Estimation for Ballistic Targets Using Passive Sensors was developed.

4 Recent Transitions

- 1. Developed A Multiple Model Filter for Impact Point Prediction of mortar and howitzer projectiles for the AMRDEC's Wide Area Protection System (P. Bradford, D. Hardiman).
- 2. An accurate algorithm for Impact Point Prediction for Short-Range Thrusting Projectiles was developed for AMRDEC (D. Hardiman).
- 3. The algorithm for evaluating the Probability of Misassociation Between Neighboring Targets was transitioned to SPARTA, Arlington, VA (G. Watson, R. Rothrock).
- 4. Developed, in cooperation with ARL, Feature-Aided Localization of Ground Vehicles Using Passive Acoustic Sensor Arrays (T. Damarla).

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