

***FUSION 2001***  
**Fourth International Conference**  
**on**  
**Information Fusion**

**Reported by Erik Blasch (AFRL/SNAS), and  
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FUSION 2001 provided a forum for fusion research, applications, and technological advances by scientists and engineers working in all aspects of information and data fusion techniques and systems. This Fourth incarnation of the International Conferences on Information Fusion was held on behalf of the International Society on Information Fusion (ISIF) in Montréal (Québec, Canada) from August 7-10 2001, during a record-breaking heat wave (35 days without rain!).

The organization and sponsorship were shared between Lockheed Martin Canada, the Network for Computing and Mathematical Modeling (NCM<sup>2</sup>) of the Centre de Recherches Mathématiques (CRM) of the Université de Montréal, Defense Research Establishment Valcartier (DREV), the Canadian Space Agency (CSA), Mathematics of Information Technology and Complex Systems (MITACS), and was under technical co-sponsorship of the IEEE AES Society.

Montréal is a bilingual cosmopolitan New World city, where French and English co-exist amicably. The chosen venue was the 30-story Delta Centre-Ville hotel, which accommodated both the conference grounds and reserved guest rooms at reduced rate for participants. Centrally located, close to historic Old Montréal, Chinatown, and only minutes away on foot from the downtown. Museums and restaurants abound in the area and were certainly well sampled by the 261 participants. The buffet-style banquet was held in the rotating penthouse restaurant Tour de Ville which gave the attendees a view of the city and the harbor and featured Canadian Cuisine from Coast to Coast. Catering for the breakfasts, coffee breaks and lunches, all of which were included with the registration, earned many plaudits.

Conference topics covered theoretical and technical advances for fusion algorithms and systems, and provided real-world applications. There were 146 technical contributions from 304 authors representing 19 countries. The format of the technical program allowed for a 25 minute presentation, and were distributed in 3 parallel sessions from 10 AM until slightly past 6 PM.

There were also 7 organized sessions on Computationally Intensive Distributed Sensor Networks (Sri Kumar, S.S. Iyengar and Jagdish Chandra), Formal Methods (Mitch Kokar, 4 papers), Image Fusion & Exploitation (Allen Waxman, 12 papers), Distributed Tracking (Jim Llinas, 7 papers), Situation Analysis and Situational Awareness (Stéphane Paradis and Jean Roy, 9 papers), Knowledge Base Role in Information Fusion (Raymond Liuzzi, 4 papers), Non-linear Filtering (Keith Kastella and Stanton Musick, 5 papers), and Probabilistic Multi-Hypothesis Tracking (Larry Stone, 5 papers). For more information, visit [www.crm.umontreal.ca/fusion](http://www.crm.umontreal.ca/fusion), which will be continually updated with conference statistics and photographs of lecturers and participants alike.

Each morning started with a plenary talk that attempted to give an overview of fusion applications not covered by the conference.

On Tuesday, the Canadian Astronaut Bjarni Tryggvason described the exhaustive space applications with which he is quite familiar, while providing the message that scientists from different disciplines should learn to fuse their research results in their



fields of expertise. In his talk entitled “*Global Challenges: Data Fusion at a Grand Scale*” he showed that a more thorough understanding of the Earth’s systems, the oceans, the atmosphere, the biosphere, its changing landmasses, and the impact that mankind has on these, will enhance our ability to better resolve the conflicting demands. Space technologies provided by Earth observation satellites and manned platforms offer a unique viewing point with many advantages when integrated with traditional monitoring methods. Earth observation satellites provide a unique platform for synoptic coverage of the Earth over large areas and extended time periods. The technical challenge is to develop the tools to assimilate the huge quantity of data that the satellites generate and to merge several types of observation to create a better systems understanding. The political challenge is to do this in time to resolve the great conflicts before they become disasters at scales not yet imagined.

On Wednesday, Guenther Palm of Ulm University provided a fascinating rendition of “*Information Fusion in Soccer-Playing Robots and Service Robotics*” complete with movies of such soccer competitions. These tournaments ask for improved methods and approaches from artificial neural networks and information fusion. Two concrete examples of information fusion in neural network architectures were presented: one for the problem of self-localization, and one for the problem of audio-visual word recognition.



Thursday morning was reserved for a panel discussion of “*higher level fusion*” chaired by Elisa Shahbazian. Mike Hinman, Jim Llinas, Alan Waxman, and Frank White discussed fusion beyond object refinement (level 1). Such topics not well researched include level 2 – situation assessment, level 3 – impact assessment, level 4 – process refinement, and level 5 – user refinement as defined by the revised community standard JDL model.

Finally on Friday, Pierre Valin (LM Canada technical committee chairman) described a “*Unified Framework for Information Fusion based on random set theory and Bayesian frameworks.*” Until recently, data fusion problems have been solved heuristically using fuzzy logic, rule-based inference, the Dempster-Shafer (DS) theory of evidence, etc. Data fusion is often just a sequential series of functions, with occasional feedback loops. Beginning in the late 1970s, however, researchers have shown how data fusion can be placed under a purely probabilistic and theoretically rigorous paradigm based on the theory of (closed) random sets. The purpose of this talk was to provide a brief “*mathematician’s overview*” of this work, especially Finite Set Statistics (FISST). Random sets provide a natural setting for data fusion in two respects: as a



natural way of formulating Multi-Sensor Multi-Target problems, and as a means of modelling ambiguous evidence.

On the first evening, the ISIF board met to discuss various matters and Jean Dézert (FUSION 2000 organizer) showed statistics from previous ISIF conferences. Figure 1 below shows that authorship by University researchers at FUSION 2001 follows the general trend of representing always roughly 2/3 of submitted papers.

FUSION 2001 - Professional origin of authors

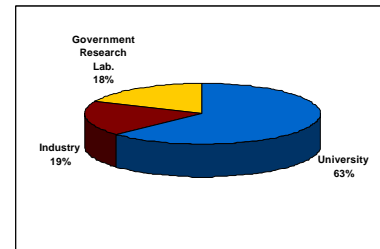


Fig. 1. Origin of Authors

Equally interesting is the constancy throughout the years of the number of authors per paper which always favors the two author partnership, as shown in Figure 2.

FUSION 2001 authors (304) repartition (146 papers)

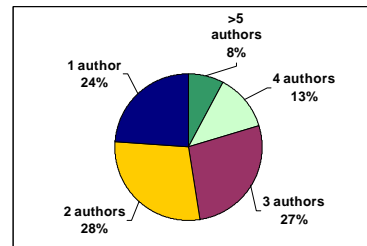


Fig 2: Authors of papers.

Parallel sessions were usually in groups of 4 to 5 presentations. As usual, Target Tracking occupied a large fraction of the attention, with 4 sessions spread out over the 3 days. Two sessions were reserved for Fuzzy Information, and also for System Design/Architecture.

Information Fusion would not be well served without the best in Information Technology. To that end, each presentation PC was provided with Powerpoint 2000 and coupled to a high intensity projector. Any necessary SW was installed ahead of time (such as codecs for movie presentation). Presenters could use a radio mouse and laser pointer to walk the audience through their seminar or use an old-fashioned overhead transparency projector. The choice was given to each presenter either to stand at the podium or to use a neck microphone.

For the convenience of the participants wishing to keep in contact with their university/industry/laboratory, 6 PCs were provided for Internet access in the Vitré room over specially installed phone lines. The latest internet versions were provided and one PC was linked to a printer, in case a



Fig. 3. The ISIF FUSION2001 Attendees

lecturer wanted to make a last minute change.

Although posters and booths were accessible at all times, a special Thursday afternoon was reserved for asking questions of the presenters, and trying on some of the software displayed. Presenting their working software, Defence Research Establishment Valcartier (DREV) presented a prototype of an object-oriented tracking and fusion system with a user interface to software choices for simulations. Jean Roy demonstrated Version 7 CASE-ATTI for the PC and Sun as a testbed for Sensor Data Fusion.

Also on hand was the Canadian Space Agency which was fostering a relationship with the fusion community for applications of fusion for space and earth analysis. Data was collected and distributed to the members of the conference. LM Canada, the CSA and DREV staffed their respective booths.

On Wednesday during the lunch break, a group photo was taken outside the Tour de la Bourse (Figure 3), and later another session was held for available chairpersons (Figure 4). As the photographs demonstrate, the mood was enthusiastic and the weather as usual sunny, and hot enough to warrant short sleeves or even shorts!

The conference consisted of four days of three parallel sessions. **Tuesday** included nine sessions.

For the Bayesian and Belief Information Fusion session lead by E. Bosse, AP Azcarraga and N Marcos of Singapore opened with rule refinements for belief fusion based on evidence. B. Chen provided a paper on Bayesian Sampling and M Xiang and C Han presented two papers on distributed detection with parallel and serial structures using a Bayesian criterion and demonstrated a fusion gain in a ROC curve

For the Tracking session lead by JP Ledardre, CY Chong, and W Torrez, D Angelova and Semerdjiev et al had a paper on stochastic sampling. MR Asharif et al of Iran

presented a paper on pose estimation for mobile robots fusing odometry and environmental maps. D Bray et al focused on an IMM approach for passive sonar application. H Chen, T Kirubarajan, and Y Bar-Shalom presented a paper entitled "Performance limits of track-to-track fusion

versus centralized estimation: theory and application". The afternoon tracking session included a paper on MHT-IMM tracking approach by S Coraluppi and C Carthel. D Dambreville et al presented a paper on search efforts for a min-max game. JG Herrero et al used an IMM for Air Traffic Control and DG Zhang et al discussed a Fuzzy Logic tracking system.

The Computational Intensive Distributed Sensor Networks session lead by S Kumar, SS Iyengar, and J Chandra included three sessions. S

Kumar opened the session with the DARPA program SensIT: Sensor Information Technology for the Warfighter – a program for developing software for distributed wireless sensor networks. JC Chen et al presented a technique for source localization for a beamforming sensor array. NSV Rao et al developed a fusion method for non-smooth (non-physical) sensor laws. S Phoha and D Friedlander used semantic information in a mobile sensor network. D Li et al discussed detection and tracking in distributed networks. H. Qi, et al used mobile agents in a distributed sensor network. T Clouqueur et al advocated value versus decision fusion for fault tolerance in target detection. A Lim developed an algorithm for information dissemination in distributed sensor networks. Finally, PW Boettcher presented a paper on time difference of arrival for acoustic bearing estimation.



Fig. 4. FUSION2001 Session Chairs

G Rogova led the Neural Networks session. M Aly used fusion for chaotic time series prediction and Z Ding et al used a chaotic NN for data association. Finally, G Rogova presented a "Reinforcement learning NN for distributed decision making."

In the Evidential Reasoning session led by JJ Sudano, four papers covered the areas of metrics and attributes. A-L Joussetme et al presented an ID metric for evidential reasoning system. J Schubert discussed force aggregation using Dempster-Shafer clustering. JJ Sudano examined Pignistic Probability transforms to combine Low and High probability events.

The Formal Methods session was led by M. Kokar included four papers. I Glockner and A Knoll introduced a natural language technique for fuzzy quantifiers. T McConaghy and T Pham presented a paper on high-level design using a hierarchical fusion scheme. M Kokar et al discussed a paper on “*Data vs. Decision Fusion in the Category Theory framework.*” SM Park showed the similarity of Appriou’s Evidential theory and Bayes Epsilon-Contamination model.

**Wednesday** included sessions on applications

The Remote Sensing /Satellite Fusion session included applications. L Bentabet et al showed fusion of SAR and road databases. JA Besada et al introduced an image-based surveillance system for an airport. T Ranchin gave examples in remote sensing data fusion.

Target tracking was revisited for another day. X Rong Li presented an expected mode augmentation to a multiple model estimator (MME). XR Li also presented part III and part IV in a series on *optimal linear estimation* that he has formulated with K Zhang. MA Kouritzin et al discussed parameter estimation for filtering problems.

Alan Waxman put together a day long session on Image fusion. Topics included biological inspiration for algorithms, use of image fusion, and metrics of image fusion techniques. Waxman et al started the session by introducing “*A prototype system for 3D color fusion and mining in multi-spectral imagery.*” The fidelity of Waxman’s work shows the promise of fusion in real-world systems. M Higgins et al presented a way to visualize spectral and spatial signatures simultaneously. S Brumby et al used genetic programming to extract features from remote sensing imagery for forest detection. G Simone et al used SAR for multi-frequency and multi-resolution fusion. In the second session on image fusion, R Eastman and Le Moigne presented gradient descent methods for multi-temporal and multisensor image registration. W Liu et al presented their ARTMAP – a framework for landcover characterization. D Fay and Waxman et al presented topics on fusion of visible, infrared, and Ladar imagery. FL Kooi and A Toet discussed stereoscopic disparity for displays. SG Nikolov et al detailed focus and context visualization for fusion of volumetric medical images. The volumetric fusion was demonstrated sufficient for user understanding showing promise for the fusion community. M Aguilar and A Garrett followed up with a neurophysiologically-based fusion for medical images. Q Zhu et al discussed co-registration of medical ultrasound and infrared imagery. Finally, A Singhal discussed multi-level Bayesian network image fusion.

Jim Llinas put together an excellent 2-part quality session on distributed tracking. D Ballantyne et al presented a branching particle-based nonlinear filter and CY Chong and S Mori discussed “*Convex combination and covariance intersection for distributed fusion.*” The paper defended a set based approach for tighter bounds on the covariance

intersection. J Uhlman et al discussed covariance intersection evaluation and C Bowman followed up with an outline of track confidence estimation for distributed information sharing. S Musick and J Layne compared distributed trackers. A Tartakovsky et al discussed invariant sequential detection and recognition of targets. Finally, HF Durrant-Whyte discussed his decentralized fusion approach using sensing networks.

A session on Classification included four papers. BV Dasarathy introduced the session with a paper on sensitivity of Elucidative fusion using a similarity metric. Jean Dezert, coordinator of Fusion 2000, derives an innovative *optimal Bayesian fusion rule* (OBFR) for multiple unreliable classifiers. M Torres-Torriti and A Jouan looked at multi-scale Markov-Random field (MRF)-based methods for SAR classification. Finally, A Nifle and R Reynaud explained a MHT with fuzzy logic for classification of missile behavior.

A session on Emerging Applications was lead by P Verlinde. P Aarabi opened the session with a paper on robust sound localization using microphone arrays. GA Fedotov introduced fusion in the context of turbulence measurements in hydrophysical applications. M Rombaut et al used fusion in computer-aided diagnosis (CAD) for myocardial viability. Finally L Valet et al used fusion in 3D seismic faces detection.

**Thursday** included sessions issues related fusion.

P Varshney lead the Decision Support/Diagnostic information session. JF Smith presented a paper on automated rule discovery that exploits opponent’s uncertainty. JF Smith followed up with another paper on fuzzy rule determination through co-evolutionary data mining. Kai Goebel discussed conflict resolution using strengthening and weakening operations in decision fusion.

The third day included another session on Target Tracking chaired by B Slocumb and CY Chong. VP Jilkov and XR Li discussed adaptation of transition probability matrix for multiple model estimator (MME). M Mallick et al discussed his out-of-sequence algorithm for multiple platforms. B Ristic et al established performance bounds for target tracking using angle-only measurements. Finally C Sotke and J Llinas discussed terrain-based tracking.

The Data Fusion Evaluation and Test Bed included four papers from a variety of interests to the fusion community. A Bruzzone et al applied fuzzy logic to multisensor data fusion. DG Zhang et al introduced a fuzzy-neural theory to electric fault detection. S Kadambe presented a paper cluster formation in a network of distributed sensors. S Xu and Z Ding presented numerical experiments on algorithms for assignment problems.

The Fuzzy Information session had eight papers. R Debon et al used veracities for fuzzy proposition determination. C Helleur introduced fuzzy clustering for a maritime picture. E Lefebvre and C Helleur followed with a fuzzy logic correlator for a recognized maritime picture. JMM Lopez et al used fuzzy priorities to for a surveillance application. JF Smith developed a fuzzy logic resource manager. V. Torra introduced an empirical fuzzy measure to determine weighted average orness (min or max). X-C Hao used fuzzy clustering for data mining. RR Yager used fuzzy systems modeling for constructing intelligent fusion procedures.

The Situational Analysis and Awareness session was led by J. Roy. J Roy opened with *Situational Analysis* which leverages data fusion for situational awareness. DA Lambert discussed situations as coupled to a common operating picture. AC Boury-Brisset discussed the DREV Knowledge manager to support the situational analysis process. AL Drozd, et. al. develops a multi-sensor integrated display system. H-W Ong et al establishes a threshold estimate of a target's origin or destination from track information for situational assessment. MK Allouche discussed the classification of temporal information in situational analysis. WC Torrez discussed information assurance in a fully netted force. JO Ross discussed an agent to assist a man-in-the-loop for threat assessment. Finally, P. Gonsalves et al, detailed an automated ISR collection management system.

An all-day session on System Design and Architectures by E. Shahbazian, A. Steinberg, and M. Hinman. C. Han et al presented a paper on fusing estimation with asynchronous measurements. TR Kronhamn discussed "*Sensor (inter) networks.*" E Shahbazian, et al, developed the *extended OODA* model with multiple loops similar to the Omnibus model for data fusion systems. SM Jameson presented his architecture that supports situational awareness in a battlefield. OM Mevassvik introduced a distributed maritime situation picture. SC McGirr lists resources available for data fusion systems and *points the reader to many fusion resources* – a valuable resource in itself for anyone looking for fusion information. A Steinberg presented his problem solving approach to data fusion. Finally, Z Tian and KC Chang discussed CDMA with multi-station data fusion.



**Fig. 5.** Clockwise from the upper right in Figure 5: a) the main table at the banquet held in the rotating penthouse restaurant Tour de Ville , b) Yaakov offering a FUSION bottle, c) the FUSION 2000 group of Dézert and Reynaud, d) ISIF members Bar-Shalom, Shahbazian and Llinas, and a quatuor possibly planning FUSION 2002 (Mallick, Rong Li, Rao, and Kirubarajan).

Various posters were presented on different topics from lasers, NN, tracking, evidential theory, explosive detection, MRI analysis of the lower back, and track association. Many of the posters were available for discussion in sections related to the related topics.

**Friday** included talks on high level fusion methods and special sessions on non-linear filtering and particle multiple hypothesis testing (PMHT).

Resource Management is key for a fusion system. K. Benameur opened the session with paper on active and passive measurement strategies. MF Contat et al. discussed an ordering method to choose a sensor and its mode. P. Dodin followed up with a paper on "*Distributed Resource Allocation under Communication Constraints.*" JP Le Cadre discussed search efforts to optimize information.

T. Kirubarajan led a session on Data Association. Z Ding et al presented a study on transiently chaotic neural networks. N Okello discussed registration and track fusion. M Rutten and J Percival discussed multipath over the horizon radar (OTHR) . Y Shi and A Zhang presented their work on "*Dynamic Clustering and Indexing of Multi-dimensional Datasets.*"

A session discussed the higher levels of fusion in a Knowledge Based Role. A Vizedom et al introduced knowledge based support for decision making. CS Aken and CL Burns discussed a theater ballistic missile reasoner. GT Capararo used fusion for a hand held system. P Chen concluded with information validity assessment.

Keith Kastella and Stan Musick put together a session on Non-Linear Tracking. Musick et al opened with a "*Performance comparison of particle methods versus finite difference non-linear systems for low SNR target tracking.*" Musick proposes to compare them based on computational burden. M Mallick et al discussed ground moving target indicators (GMTI) with non-linear filters. MI Heifetz et al conceived the idea of a two-

step nonlinear filter for a relativity experiment. S Mori and C-Y Chong introduced a "*Qualitative Evaluation of Poisson Point Process Approximation.*"

A session on Target Recognition and Identification was led by EP Blasch. S Allen showed FLIR feature ship recognition. EP Blasch and T Connare presented a paper on "*Improving track accuracy through Group Information Feedback.*" E Menard et al discussed Valuation-based systems for object recognition. The value based system is a combination of evidential reasoning in a Bayes net. Finally, EA Semerdjiev et al, could not attend, but wrote a paper on multiple model sea mine tracking.

The final session was led by Larry Stone on Particle Multiple Hypothesis Testing (PMHT). LR Streight et al discussed multiple target tracking using a histogram-PMHT. T Luginbuhl, Y Sun, and P Willet presented a track management system for PMHT. M Malyutov et al discussed

multi-trajectory estimation in noise and clutter. SJ Davey et al used PMHT in OTHR. Finally, C Hue used multiple receivers in PMHT.

The sessions covered a variety of topics and many more papers were submitted than could be accepted. Next years topics will include Level 5 User Refinement in Data Fusion, comparisons on Evidential and Bayesian Reasoning, and Sensor Fusion in Target Tracking.

The Proceedings were available on-site for papers and posters, while the plenary sessions and panel discussions will be made into Volume 3 and sent by regular mail to all participants. The CD-ROM is available for both NT and Unix compatible systems and includes a copy of the FUSION 2001 website in which the program schedule points to pdf versions of all the papers. It also includes a search engine that can search for keywords in the abstracts of papers, names of all authors, as well as the first 2,000 words of all papers (courtesy of Paul Geanta, FUSION 2001 webmaster).

Every participant was handed a conference bag stuffed with goodies in addition to the Proceedings and CD-ROM:

1. A FUSION 2001 poster which illustrates fusion of RADARSAT imagery with DTED maps that color code altitude information (courtesy of CSA and CCRS), together with Chromatek 3-D glasses that allow 3-D viewing of the poster using altitude-derived color-coding.
2. A poster interpretation guide to explore the Montréal area.
3. Three maps to explore Montréal on foot, by public transportation, or by car.
4. IEEE courtesy material such as the AESS October 2000 Jubilee issue and also the July 2001 issue, the IEEE AESS 50-year cumulative index on CD-ROM, the IEEE Spectrum July 2001 issue, and an IEEE ball-point pen.
5. Montréal guides: the official Tourist Guide and map, a Restaurant guide, and "What to do in Montréal".

A review of the success of FUSION 2001 would not be complete without a collage of some *candid photos* taken at the banquet (Figure 5) and during the conference coffee breaks (Figure 6).



**Fig. 6.** In the leftmost column of Figure 6 are a) Palm, Shahbazian and Iyengar, b) Mallick, Mori, and Musick detailing tracking results, c) a large group including LeCadre and Stone. In the center column are d) the authors of this report discussing the conference, e) White and Shahbazian visiting the Canadian Space Agency (CSA) booth, f) Shahbazian and Blasch, g) Llinas and Waxman discussing their organized sessions. In the rightmost column are h) Rong Li, Bar-Shalom, Kirubarajan and Blasch, i) the Canadian contingent of Bossé, Roy, Paradis, and Shahbazian taking a break from their booth, and k) the organizing staff of LM Canada flanking Helleur.

Thanks goes out to all who helped with the conference's success - those that participated, those who kept the webpage informative, and the organizing committee for the smooth operations. Hope to see everyone at Annapolis, MD (USA) in July 2002. For updates, check the ISIF webpage [www.inforfusion.org](http://www.inforfusion.org).

The fifth ISIF conference will be chaired by T. Kirubarajan, XR Li, and D Blair. The Annapolis, MD (USA) site will be close to the historic government buildings and located near a set of world-class attractions including the Smithsonian and NASA's aviation and space museums. Transportation to the facilities will be available from the Dulles and Baltimore airports. Anyone wishing to sponsor a special session should contact the chairs. For updates and information, visit [www.fusion2002.org](http://www.fusion2002.org).