Sensor Fusion 1997

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This is the second offering of the *Optical Engineering* special section on sensor fusion, a field that has continued to experience significant growth during the past year. The response to the call for papers was more enthusiastic than last year, which is a reflection on the success of the last special section [*Optical Engineering,* Vol. 35(3), March (1996)] and the ensuing increased awareness of this avenue within the sensor fusion community. True to form, as the deadline approached, requests for extensions came in and the effective cut-off date started slipping. However, with a flexible carrot and stick approach, we are happy to note we are bringing out the sensor fusion special section on schedule, covering some of the excellent research carried out recently in this field.

This special section, a collection of 17 papers from the United States, Canada, and Australia, covers a broad range of sensor fusion related topics, with multisensor/multitarget tracking being the most predominant, signifying its importance to the defense community and the consequent funding support. Most of the studies fall under one or more of the three basic facets of the field, namely architecture, algorithms, and applications. The collection starts with a study by Dasarathy that presents and discusses alternative architecture for fusion of decisions from sensors with limited decision capabilities. The traditional role of the fusion processor in multiclass decision environments has been to combine and exploit the complementary nature of information available from the sensors across the entire set of decision choices. In this study, a significantly different role of the fusion processor, in terms of combining information from sensors that may individually be limited to specific decision choices only, is explored. Architectures designed to exploit this scenario are analyzed to determine their optimal domains of application.

The second paper, by Rao, presents the Nadaraya-Watson estimator in its new role as a generic tool for sensor fusion in environments, wherein the underlying sensor fusion error densities are unknown, but sufficient information in terms of training samples are available. The study starts with a detailed theoretical treatise on the Nadaraya-Watson estimator, setting it within the sensor fusion framework, followed by two examples that illustrate the performance of the estimator relative to nearest neighbor and neural network approaches. The study concludes with specific suggestions for future research.

The next study, by Bossé and Roy, offers a Dempster-Shafer (evidential reasoning) approach to the problem of fusion of target identity information obtained from diverse sources. The problem is defined in the context of naval warfare, wherein the decision makers require a ''best estimate'' knowledge of both ''where it is'' and ''what it is'' type of information, followed by intent or behavioral data. This study, however, addresses just the limited objective of ''what is it.'' A detailed discussion of the problem environment is presented followed by a review of the Dempster-Shafer theory and an assessment of the associated computational complexity. An example is included to illustrate the methodology.

The fourth presentation, by Samarasooriya and Varshney, employs the other popular approximate reasoning approach, namely fuzzy logic, for tackling the problem of decentralized signal detection in the presence of additive noise. The sensor measurements are deemed to be imprecise and thus necessitating and justifying the use of approximate reasoning tools. The observation space is defined by fuzzy partitions. The study first defines the concept of fuzzy information systems and develops the decentralized hypothesis testing within this context. A discussion of the associated data compression issues is also presented. An experimental comparison with a traditional crisp logic based fusion process would have been beneficial in proving the efficacy of the proposed approach in a practical environment.

The next study, by Dasarathy, combines elements of the previously mentioned two subcultures of approximate reasoning, namely evidential reasoning and fuzzy logic, to address the twin problems of target identity and track fusion. The method is more heuristic and less analytical than the previous study, but demonstrates its effectiveness through application to real-world data from multiple ground based sensors (radars). The real-world example not only shows quantitatively the benefits of fusion of information from multiple sensors, but also brings out the potential for recovery from initial sensor errors that is unique to the fuzzy evidential reasoning approach in contrast to traditional crisp fusion logic.

The sixth paper, by Chang and Fung, also addresses the problem of target identification in conjunction with the tracking problem. The algorithms employ Bayesian networks, an approach that should by now be familiar to those who have followed the earlier studies of these authors. The proposed methodology integrates the model based target identification process with the multiple hypothesis tracking (MHT) approach. The intended application involves two types of sensors, electronically scanned radar (ESA) and an infrared search and track (IRST).

The next contribution, by Sundareshan and Amoozegar, is an exposé on the use of neural networks for track fusion. The study offers a system architecture that combines the fusion function of a neural net with the tracking function of a Kalman filter. Some examples are included to bring out the details of the implementation and illustrate its effectiveness.

The eighth study of the set, by Ding and Hong, is once again a study of the multisensor/multitarget tracking problem. Both static and dynamic models are considered. The study envisages multiple platforms for the multiple sensors, which also brings into consideration communications aspects of the fusion process. The interacting multiple model (IMM) algorithm is chosen among the many available choices. Computer simulation of a two-dimensional single target tracking problem is offered to bring out the differences in the performance and computational complexity of the static and dynamic approaches. The communication needs, however, are nearly the same for both algorithms.

The ninth paper, by Mohandes, Bogner, and Bouzerdoum, deals with the problem of track association for fusion of information from three over-the-horizon radars. Two alternative methods of feature extraction, the first based on Hough transforms, and the second based on track affinity measures, are investigated, the latter showing significantly less error rates. In each case, both neural net and classical decision approaches are employed for the classification task, and comparative results are furnished.

The next study, by Li, Leung, and Blanchette, also employs Hough transforms as one of the alternatives for track initiation. The other is a multisensor logic based approach. The former is a batch technique while the latter is a sequential one. Both these approaches are extended here to the multisensor environment. The performance of the proposed system is investigated using both simulated as well as real-world radar data. The real-world data is used to demonstrate the benefits of fusion of data from multiple sensors.

Following this collection of target tracking studies is a pair of studies dealing with some aspects of image data fusion. The first of these, by Kinser, employs pulse-coupled neural networks (PCNN) for performing fusion of information within multiple images from the viewpoint of target detection. The study first offers a brief review of PCNN and fractional power filters (FPF), a composite Fourier filter that is the other component of the proposed image fusion system. Included is an example illustrating pictorially the solution obtained for an interesting target detection problem, namely, an ice cream cone in a child's hand.

The twelfth study, the second image fusion related paper, by Sims and Phillips, offers a thorough relative evaluation of three image data fusion algorithms previously reported in the literature by other researchers. The relative assessment effort leads to a new alternative implementation as well. The effect of target signature variation on each of these methods is also studied and a new distortion metric is offered.

The next one in this series, by Smith and Nandhakumar, addresses a significantly different facet of fusion of relevance to computer vision. The study offers four token based, rigid body structure from motion (SFM) algorithms modified to recover structure from nonrigid motion using temporal fusion concepts. Results obtained by using simulated imagery are included to assess the performance of the modified algorithms.

The fourteenth offering, by Brooks and Iyengar, deals with the problem of fusion of time critical readings for dynamic distributed sensor fusion involving competitive sensors. The challenge lies in real-time interpretation of conflicting readings from the competing sensors in the context of sensor noise. A formal problem description is first presented, followed by details of the approach and a simulation exercise in terms of a target tracking problem. The study concludes with a comparison of the proposed method with weighted average, Kalman filter, Bayesian interface, and Dempster-Shafer inference, from conceptual as well as computational viewpoints.

The next study, by Zhou, Leung, and Bossé, tackles the problem of registration of multiple mobile sensors using yet another variant to the well-known Kalman filter. The variant, called the parallelized extended Kalman filter (EKF) is described, followed by some computer simulations to bring out the effectiveness of the proposed scheme.

The fifteenth paper, by Harney, describes an information based approach to the twin problems of performance estimation and optimal allocation of requirements among sensors. This multisensor fusion problem is defined in the context of a target recognition task, and the study offers a set of heuristics based on the long-standing Johnson's criteria used for characterizing information content within imagery data. The resulting methodology is extended to assess performance of multiple sensors and the potential for sensor selection and requirements allocation is discussed.

The last one, by Wann and Thomopoulis, describes the application of a self-organizing neural network, Dignet, to the problem of data fusion in a multiradar environment with three nearly colocated radars for target detection. The neural net is used first for performing feature level clustering, and the results thereof are fed into a fusion neural network. The paper starts with a brief description of the Dignet, followed by details of its adaptation to the data fusion function and the associated two-stage architecture. Its application to the radar data fusion problem along with some experimental results are also presented.

Thus, the papers selected for this special section span a wide array of architectures, algorithms, and applications dealing with different aspects of the exploding field of sensor fusion. It is interesting to note in this context that the review process gives the editor a chance to personally experience the role of a central fusion processor in trying to fuse the information/decisions from the local processors (otherwise known as the unsung anonymous reviewers), which are sometimes conflicting (more often than one would like) and always at different levels of detail. Most of these conflicts in review opinions have been resolved by the fusion processor editorially in favor of the authors, giving them the opportunity to rebut and/or revise the manuscripts accordingly.

It gives me great pleasure to announce that based on the success of this effort, the next special section in *Optical Engineering* on sensor fusion is being planned for February 1998 and I look forward to contributions from the journal's readership. The call for papers and schedule appears in the *Optical Engineering* editorial schedule. I would also like to take the opportunity to invite the readers to the SPIE conference on sensor fusion being held as part of the SPIE 11th Annual International Symposium on Aerosense during April 20 through 25, 1997, in Orlando, Florida.

On behalf of *Optical Engineering* and myself, I would like to express our appreciation to the authors for their contributions and acknowledge the reviewers for their invaluable help and dedication to making this a truly worthwhile addition to the sensor fusion literature. On a more personal note, I would also like to thank Professor Brian Thompson for giving me the opportunity to bring out this special section on sensor fusion. My thanks are also due to Mr. Tom Baumbach, Executive Vice-President, Dynetics, Inc., for the logistic support and encouragement for these professional activities.

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