Sensor Fusion 1996

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The past decade has seen an explosive growth in the field of sensor fusion and SPIE has played a crucial role in this growth by sponsoring annual spring and fall conferences on sensor fusion. It is thus fitting that *Optical Engineering*, the flagship publication of SPIE, is offering this special section, the first in what is planned to be a series, dedicated to sensor fusion developments. Nearly a dozen papers dealing with various facets of the area covering fusion at different levels, such as data, feature, and decision levels, have been selected for this section. The field of sensor fusion has been characterized in the literature in terms of levels, not only of the inputs/outputs of the fusion process, but also of the objectives of the fusion process, the latter especially in the area of defense applications as defined by the data fusion panel of the Joint Directors of Laboratories (JDL). Here we are using the term fusion levels to be that defined by input/output characteristics. Although this trilevel (data, feature, and decision levels) categorization has been the traditional view of the field, I would like to take this opportunity to present a more comprehensive input-output descriptor-pair-based categorization of the field.[1] Viewing sensor fusion as a process with inputs and outputs, the process can be categorized by the specific combination of the type of inputs and outputs linked to the process. This is a more effective representation than one where the process is described in terms of either inputs or outputs alone, especially when they both are not in the same domain of either data, or features, or decisions. Most of the papers in the field as well as the ones presented here in this section can be mapped onto the sensor fusion space defined here. Although there exists a school of thought that fusion at the lowest possible level in a given scenario is the best approach, since the level of detail in the information is highest at that level, one should note that the corruption of information due to noise is also the highest at that level. The process of extracting relevant information from the data, in terms of features and decisions, while throwing away the details, may also help in reducing the noise. Accordingly, an exhaustive exploitation of the sensor fusion potential in any given application is best based on a model, as shown in Fig. 1.

While many of the papers presented here are clearly devoted directly to the development and applications of sensor fusion concepts and techniques, a few tackle some related aspects such as data association, feature extraction, and assessment, which indirectly contribute toward successful implementation of the fusion techniques. Further, I am happy to note that quite a few of the papers also present application results of the research to real-world data of one kind or another.

The first paper (selected for this status on the basis of recommendations of one of the reviewers that it would form a good yet easy-to-read introduction to sensor fusion for the uninitiated reader), by Dasarathy, is an analytical exposition of the alternative temporal decision in–decision out fusion strategies in the context of a parallel sensor suite with two independent sensors. The paper clearly delineates the domains defined in terms of the individual sensor characteristics in which fusion would be beneficial under the different recursive temporal fusion strategies.

The next paper, by Rao and Iyengar, deals with the distributed decision fusion problem in a nonparametric domain, i.e., one in which probabilistic descriptions are not available *a priori*. They offer three alternative methods for deriving an approximately optimal fusion rule based on acquiring a sufficiently large training sample set.

The third paper, by Samarasooriya and Varshney, describes a sequential approach to asynchronous decision
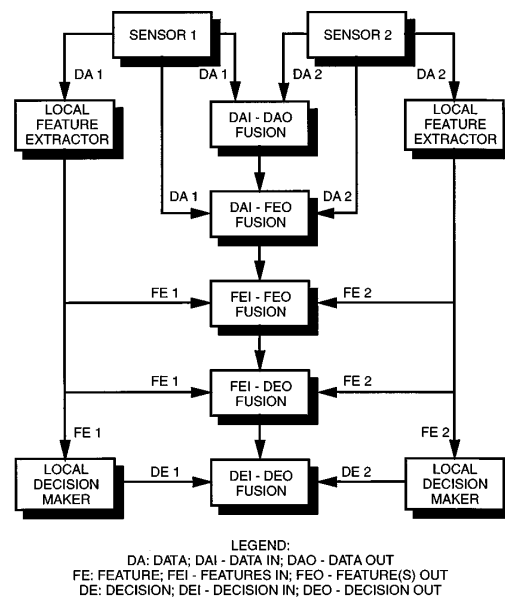

LEGEND:
DA: DATA; DAI - DATA IN; DAO - DATA OUT
FE: FEATURE; FEI - FEATURES IN; FEO - FEATURE(S) OUT
DE: DECISION; DEI - DECISION IN; DEO - DECISION OUT

Fig. 1

fusion. This is essentially an asynchronous variant to the decentralized version of the well-known Wald sequential hypothesis testing previously discussed by several authors in the literature on distributed detection.

The fourth paper, by Dasarathy, offers an adaptive fusion processor architecture for fusion of a mix of inputs acquired at varying levels of detail: data, feature, and/or decisions, with the output being at the decision level. Initially, four alternative approaches are considered from which the adaptive fusion paradigm is selected for detailed implementation and evaluation using real-world data. The experimental evidence provided demonstrates the quantitative (in terms of improved object detection rates) as well as qualitative benefits (in terms of providing object identification in addition to object detection) of the approach.

The next one in the set, by Toet and Walraven, is a significantly different one in that it accomplishes fusion with both input and output at the data or pixel level. It also offers examples based on real-world data to demonstrate the effectiveness of the color mapping algorithm used to produce a fused false color image rendering of the two input gray-level images.

The sixth paper in the series, by Romine and Kamen, investigates the different aspects of the problems of modeling and fusion of radar and imaging sensor data in the target tracking context. It first offers a method of extracting angular position information from the 2-D image intensity data and develops an appropriate model thereof. This is followed by a presentation on the fusion of position information, which in essence is another example of fusion at the data level. The paper offers simulation examples to illustrate the methodology, although to judge the effectiveness of the algorithms, testing with real data would be necessary.

Appearing next is the paper by Maheshkumar et al., which deals with the problem of integration or fusion of data from complementary sensors, i.e., nonidentical sensors that individually offer only partial information of the totality required for the entity under view. The work presented is essentially an extension of earlier work in this area by others in terms of proposing an alternative model for the non-Gaussian random noise (called clouds) and a computationally more efficient method for detection and removal of this cloud.

The eighth paper, by Pieper, Cooper, and Pelegris, is once again a study of fusion at the data level wherein the range information from two passive sensors are integrated to derive an estimate of the target range using the principle of two orthogonal baselines. The paper discusses both the single- and dual-baseline models as well as the associated accuracies and limitations under different geometries.

The next one in the set, by Leung, deals with a problem often associated with the fusion process, namely, data association. Prior to data fusion it is critical in many applications such as target tracking to be able to associate incoming data with the right track before applying the fusion rules and algorithms. The study discusses a neural net approach to the data association problem based on a modified Hopfield network. The paper includes examples of the application of the methodology to real-world data.

The last but one entry, by Liu and Chang, discusses the usefulness of the Bayesian network as a feature-level fusion tool; unfortunately, the example from the real world used to illustrate the methodology considers inputs from a single sensor only.

The final paper, by Hoekstra and Nandhakumar, discusses the behavior of features derived from multiple sensors. The emphasis is not so much on fusion methodology as it is on the invariance and hence the robustness of the features derived from multisensor imagery.

Although most of these papers explore the potential of fusion at one specific level or another, in many applications such as target recognition, the potential for fusion exists at more than one level and, as illustrated in Fig. 1, a practical solution in the real world has to take advantage of all these avenues. This is attempted to a limited extent in the paper by Dasarathy on adaptive fusion paradigms.

On behalf of *Optical Engineering* and myself, I would like to express our thanks to the authors for their contributions and acknowledge the reviewers for their invaluable help and dedication in making this a truly worthwhile addition to the sensor fusion literature. On a more personal note, I would also like to thank Prof. Brian Thompson, the editor of *Optical Engineering*, for giving me this opportunity to bring out this special section series on sensor fusion.

It gives me great pleasure to announce that based on the success of this effort, the next special section on sensor fusion has been planned for March 1997, and I look forward to contributions from the *Optical Engineering* readership.

References

1. B. V. Dasarathy, *Decision Fusion*, IEEE Computer Society Press, Los Alamitos, CA (1994).

Belur V. Dasarathy is a senior principal engineer on staff to the executive vice-president at Dynetics, Inc., Huntsville, Alabama. His current R&D interests include sensor fusion, pattern recognition, image analysis, fuzzy logic, neural nets, data compression, machine intelligence, and related topics in the design and development of automated optimal decision systems as applied to a broad spectrum of multispectral and multisensor environments arising in various civilian, commercial, and defense applications. He earned his PhD in engineering at the Indian Institute of Science, Bangalore, where he later served as a founding member of the faculty of the School of Automation. His other associations include Southern Methodist University, Computer Sciences Corp., and Intergraph Corp., Huntsville, Alabama. He has also served as an adjunct professor at the Department of Computer Sciences at the University of Alabama in Huntsville for several years. Dr. Dasarathy has authored three books for the IEEE Computer Society Press, *Nearest Neighbor (NN) Norms: NN Pattern Classification Techniques, Decision Fusion*, and *Image Data Compression—Block Truncation Coding*. He has more than 140 technical papers to his credit. In 1994, he was honored as a Professional of the Year by the Huntsville Area Technical Societies Organization. He has been a reviewer for several international journals and organized and chaired various conferences. He is a senior member of the IEEE. He was the chairman of the IEEE-Huntsville Section from 1992 to 1993. In prior years, he served as its vice-chair and programs chair and as the editor of the section newsletter, *Livewire*. Earlier, he was the chair of the Huntsville IEEE Computer Fair and the Rocket City seminars.