Sensor Fusion 1998: A Case for Intelligent Fusion

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This is the third offering of *Optical Engineering* special sections on sensor fusion, a field that has continued to flourish at a rapid pace during the past year. This growth was also reflected in the response to the call for papers, which was indeed encouraging considering the multitude of conferences and special issues in this field. The schedule this year was a month ahead in the calendar compared to the past two special sections, and meeting the deadlines proved to be a greater challenge. Fortunately, thanks to the cooperation of the authors, reviewers, and the SPIE publication department, we are happy to note that we have been able to bring out a special section of excellent quality and on schedule.

Breaking tradition, I choose not to offer a paper-by-paper overview of the collection, thereby maybe forcing the readers to take the time to read through at least the abstracts of all the papers. Instead, I would like to make some general comments on the studies presented in this collection and simultaneously pontificate, if I may, on the future directions I hope to see in the sensor fusion arena that would make research in this field both interesting and productive. This special section, a collection of 18 papers from the U.S., Canada, and Europe, covers a broad range of sensor fusion related topics, which fall under one or more of the three basic facets of the field, namely, architectures, algorithms, and applications. A third of these, presented first, cover various aspects of decision level fusion in the context of detection, recognition, and identification of objects in multi-sensor/multi-decision process environments. Offered next are nearly as many studies dealing with various aspects of tracking these objects in multisensor environments, including the related problem of data association. Following these are three papers that discuss image level fusion techniques and associated issues. The collection concludes with a few studies that address other miscellaneous topics such as sensor measurement scheduling, sensor alignment, and specific algorithmic tools such as vector space methods, genetic algorithms, and simulated annealing that are applicable to various sensor fusion related issues. Thus, the majority of the studies in this collection, as well as those in the overall sensor fusion literature, address the problem of fusion with the goal of answering either of the questions ''what is it?'' (object identification) or ''where is it?'' (object tracking). But it is much more beneficial to investigate an integrated approach to these two coupled problems since quite often knowing ''where it is'' helps in determining ''what it is'' and vice versa. Such an integrated temporal fusion approach should be flexible enough to fuse the information pertaining to either of the problems as and when it becomes available without necessarily being dependent on updates relating to both of the issues being available simultaneously.

Experience over the years has brought home the fact that fusion should not be an end in itself but only a means to improve the overall system performance. As experiments with real data have shown, it is conceivable that in many instances fusion does not necessarily enhance performance, especially if one were to consider the costs associated with the fusion function in terms of additional computational and communication loads, not to mention the costs of additional sensor system complexities. It is therefore necessary that the fusion function should be construed as an intelligent process which should be capable of deciding not only what to fuse and how to fuse but also when to fuse. The task of the intelligent process is therefore to define an optimal partitioning of the multisensor, multi-temporal decision space both in the parametric and temporal dimensions. The intelligent fusion processor should also be capable of learning from past performance and adapting to the changing environment. That is, the decision space partitioning has to be a dynamic on-going activity. For example, as shown in Figure 1, the decisions made by the fusion system may be employed as feedback to the individual sensor-decision subsystems to be a teacher, albeit an imperfect one, in monitoring their performance. Pattern recognition techniques for learning with an unfamiliar teacher,[1,2] based on the concept of ''learning about the teacher aids learning under the teacher,'' may be adapted with the fusion system being the unfamiliar teacher whose performance quality is learnt simultaneously while it is being utilized to monitor and correct the behavior of the individual subsystems. Resulting improvements in the behavior of the subsystems in turn leads to better performance of the fusion system, thus making the unfamiliar teacher a dynamic one, requiring adaptation of more advanced concepts such as learning under a vicissitudinous teacher.[3,4] This mutually reinforcing learning architecture linking the individual sensor-decision subsystems and central fusion processor should also be made capable of distinguishing as to when fusion may or may not be profitable. Also, fusion systems have

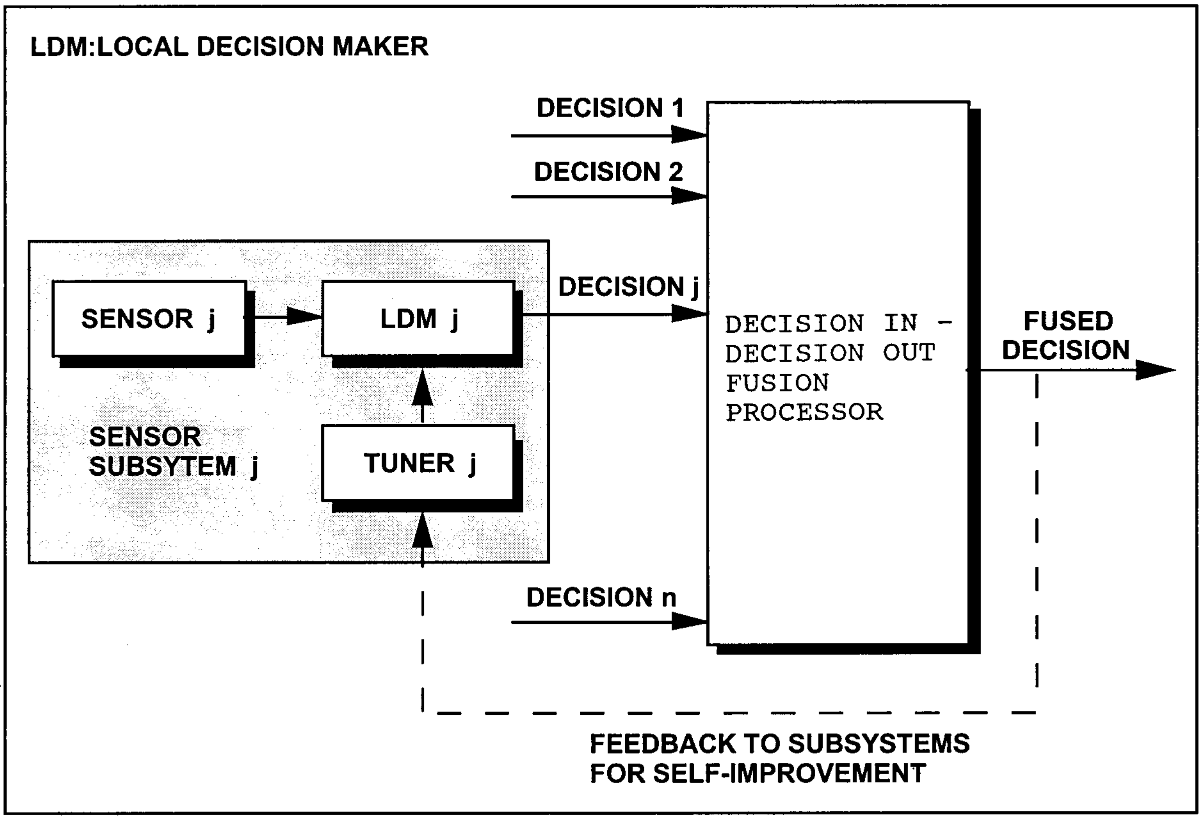

Fig. 1 A self-improving fusion system architecture.

generally been designed based only on an *a priori* knowledge of the problem environment and operate on the basis of pre-defined fusion logic, be they crisp (deterministic), probabilistic, or fuzzy in nature, with no specific learning phase. It would be worthwhile to exploit the scope for learning the optimal fusion logic using a set of known ground truth data in a manner similar to the way pattern recognition systems are trained. These intelligent fusion avenues, which are definitely not meant to be exhaustive in scope, are but examples of the lines of investigation that can hopefully further the cause of sensor fusion.

I would like to take this opportunity to invite the readers to the SPIE conference on Sensor Fusion being held as part of SPIE 12th Annual International Symposium on Aerospace/Defense Sensing Simulation and Controls, April 13–17, 1998, at Orlando, Florida, wherein some initial forays along these avenues are scheduled for presentation. On behalf of *Optical Engineering* and myself, I wish to express our appreciation to the authors for their contributions and acknowledge the reviewers for their invaluable help and dedication to making this a significant and worthwhile addition to the growing sensor fusion literature. On a more personal note, I would also like to thank Professor Thompson, the previous editor of *Optical Engineering*, for having given me the opportunity to present this set of three special sections on Sensor Fusion over the past three years.

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