Sensor Array and Multichannel Signal Processing

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This article follows the ICASSP 2011 Trends in Sensor Array and Multichannel Signal Processing (SAM SP) expert session and represents our views on continuing and emerging research areas in this field.

INTRODUCTION

Over the last two decades, SAM SP has expanded beyond its traditional array processing roots, and multichannel and multisensor systems are now prevalent in virtually every SP discipline and application. Consequently, there is considerable overlap with specific application areas such as communications, acoustics, and sensor networking. In the following, we sketch trends, applications, and tools. Classically, more than one sensor implied a gain in signal-to-noise ratio. Today multisensor approaches yield spatial and temporal information, the ability to separate multiple sources, sensing diversity to overcome channel impairments, and spatially distributed sensing. Statistical signal processing plays a fundamental role for new problem areas, yielding models, optimal algorithms, and performance analysis and bounds. Of particular note are the steady trends in multiple input, multiple output (MIMO) radar; the distributed interplay between sensing, communications, and processing; dimensionality reduction; and fusion of disparate sensor modalities.

MIMO RADAR AND COMMUNICATIONS

MIMO system theory has steadily progressed to practice over the last decade, especially in wireless communications where processing over multiple simultaneous communications channels leads to dramatic gains in channel quality and throughput. Inherently, MIMO exploits channel diversity and allows the transmitter and receiver to select channel modes that yield the best signal-to-noise ratio. The extension of pairwise transmission–reception to consideration of a network of nodes continues to be of significant interest, enabling tradeoffs in throughput, power, interference, and other system attributes. Conventional array processing continues to benefit from the development of algorithms that are robust, near field, or deal with calibration issues, and utilize multidimensional arrays. Beamforming and source separation benefits from continued development of multisensor algorithms and their application in communications and other disciplines, where each new problem brings its own flavor of side information and restrictions. Recently, MIMO has been extended to enhance the state of the art of radar technology. For MIMO radar with widely separated antennas, angle diversity is exploited for enhanced target detection and parameter estimation performance [1]. For MIMO radar with colocated antennas, waveform diversity is utilized to achieve a large virtual array and hence a much improved spatial resolution [2]. Compared to conventional radar, MIMO radar offers the advantages of smaller size, lighter weight, lower power consumption, and less cost in certain applications. The notion of MIMO active sensing is expected to attract continued interest from theorists and practitioners in diverse application areas including through-the-wall sensing, acoustic imaging, and biomedical applications.

[STATISTICAL SIGNAL PROCESSING PLAYS A FUNDAMENTAL ROLE FOR NEW PROBLEM AREAS.]

COMPRESSED SENSING AND DIMENSIONALITY REDUCTION

A critical component for successfully unifying multiple sensor processing is exploitation of inherent sparsity in the problem. This enables dimensionality reduction that can be quite significant, typically by projecting the data into a lower dimension. When the projection is information preserving, then dramatic reduction in processing complexity can be achieved. There are now many examples of this in array processing and beamforming, MIMO radar, source localization, channel estimation in communications, and other areas [3]. This rapidly maturing area continues to see significant attention to such problems as application modeling, analog-to-digital sampling techniques, achieving robustness to noise and outliers, and managing computational complexity.

CONVEX OPTIMIZATION FOR SAM APPLICATIONS

Many signal processing problems can be cast in an optimization framework, often converting a nonconvex problem to a convex one using the dual formulation. Although the solution may not be fully optimal, this approach can nevertheless yield a tractable problem statement, and convex optimization computational tools are now readily available and reaching significant levels

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of maturity. Similarly, maximum likelihood or other estimators are typically at least locally convex so that with a reasonable initial guess a convex optimizer can provide an optimal estimate. Examples in the SAM SP area include transmit beampattern design in MIMO systems, robust adaptive array design, and filter synthesis [4].

DISTRIBUTED PROCESSING AND LOCALIZATION

The continuing strong trends in distributed processing and sensor networking provide a wealth of issues for the SAM community. These include accelerating and improving consensus and gossiping algorithms, and making them robust to such issues as timing, noise, and communications imperfections. The inherent assumptions of synchronization, localization of nodes, and stationarity are all subject to the need for initialization and error reduction. Localization is an important problem, using both passive and active techniques, combining measurement modalities such as spatial and temporal joint processing, in such areas as radio and acoustics. Along these lines, distributed problems in angle-of-arrival, time delay estimation, and signal strength estimation (to name a few), provide the underlying information extraction to enable network localization solutions [5].

COGNITION AND FUSION

Mobile systems are increasingly equipped with more sensors, more processing, and more communications, and their interplay provides a rich area for algorithm development, analysis, and experimentation. Inherent in their interplay is the need to balance communications and processing, and characterization of this tradeoff continues to be an active trend. This also includes power consumption and allocation, where miniature nodes have limited energy lifetime and must preserve this precious resource. Many investigators continue to address dynamic spectrum access [6] and cognitive radio generally, where capability is significantly enhanced by exploiting sensor arrays. Communications relay is similarly of strong interest both practically and theoretically. We expect the trend to more intelligent sensing coupled with networking to continue strongly, incorporating more sophisticated signal processing techniques in mobile nodes.

More and more systems are incorporating mobility and dynamics, and these provide a wealth of new SAM SP challenges. In robotics, sensors are combined to provide geolocation, scene understanding and perception, and enable autonomy. Strong trends to multimodal sensing continue to accelerate the need for fusion that is robust and low complexity, yet achieving high performance. We expect this trend to continue and grow, incorporating learning and dynamics in new and interesting ways [7, 8].

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REFERENCES

[1] A. H. Haimovich, R. S. Blum, and L. J. Cimini, "MIMO radar with widely separated antennas," *IEEE Signal Processing Magazine*, vol. 25, no. 1, pp. 116–129, Jan. 2008.

[2] J. Li and P. Stoica, "MIMO radar with colocated antennas: Review of some recent work," *IEEE Signal Processing Magazine*, vol. 24, no. 5, pp. 106–114, Sept. 2007.

[3] E.J. Candes and M.B. Wakin, "An introduction to compressive sampling," *IEEE Signal Processing Magazine*, vol. 25, no. 2, pp. 21–30, Mar. 2008.

[4] A. B. Gershman, N. D. Sidiropoulos, S. Shahbazpanahi, M. Bengtsson, and B. Ottersten, "Convex optimization-based beamforming," *IEEE Signal Processing Magazine*, vol. 27, no. 3, pp. 62–75, May 2010.

[5] N. Patwari, J. N. Ash, S. Kyperountas, A. O. Hero, R. L. Moses, and N. S. Correal, "Locating the nodes: Cooperative localization in wireless sensor networks," *IEEE Signal Processing Magazine*, vol. 22, no. 4, pp. 54–69, July 2005.

[6] Q. Zhao and B. M. Sadler, "A survey of dynamic spectrum access," *IEEE Signal Processing Magazine*, vol. 24, no. 3, pp. 79–89, May 2007.

[7] J. B. Predd, S. B. Kulkarni, and H. V. Poor, "Distributed learning in wireless sensor networks," *IEEE Signal Processing Magazine*, vol. 23, no. 4, pp. 56–69, July 2006.

[8] D. Merkle and M. Middendorf, "Swarm intelligence and signal processing," *IEEE Signal Processing Magazine*, vol. 25, no. 6, pp. 152–158, Nov. 2008.

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