Radar Methods in Urban Environments

Arye Nehorai
WASHINGTON UNIVERSITY THE

10/26/2016
Final Report

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We developed a new algorithm for sparse imaging of perfect electric conducting targets based on higher order sources or multipoles. We devised a strategy to select the optimal orders without needing any a priori information on the target by taking advantage of some analytical considerations in a canonical case. We developed a data-driven method for target detection in nonstationary environments. We employed drift detection algorithms to detect changes in the environment, which are utilized to intelligibly update the statistical detection algorithms to gain improved detection performance. We developed a method for joint design of amplitudes and frequency-hopping codes for frequency-hopping waveforms using a collocated multiple input/multiple output radar system. We formulated a novel game theory based model and propose two joint design algorithms. We considered a system of two point scatterers under a general multistatic configuration and investigated the effect of multiple scattering in the detection and estimation of scatterers. We investigated the self-calibration problem for perturbed nested arrays in the presence of gain and phase errors, and developed robust algorithms to estimate the direction-of-arrivals (DOAs). We developed an adaptive Gaussian mixture learning algorithm in posterior-based distributed particle filtering, in which posteriors are approximated as Gaussian mixtures for wireless communication. We developed polynomial-time algorithms to compute the performance bounds on convex block-sparsity recovery based on fixed point theory and semidefinite programming. Recently, we also developed new target detection methods using weather radars and electromagnetic vector sensors. We analyzed the asymptotic DOA estimation performance of sparse linear arrays, and derived the corresponding Cramér-Rao bound.
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11/9/2016
Radar Methods in Urban Environments

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August 2011 – July 2016

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1 Final Accomplishments (August 2015 to July 2016)

We developed an innovative algorithm for sparse imaging of perfect electric conducting targets based on higher order sources or multipoles [J2]. EM imaging has emerged as a promising technology in the fields of radar, biomedical imaging, navigation, and remote sensing in recent years. We demonstrated that, due to the directivity of higher order sources, the imaging capabilities of the algorithm are enhanced. We showed that the zero-order sources are more suitable for the reconstruction of the convex parts of target boundaries, whereas the higher order sources are more appropriate for the concave parts of the boundaries. We devised a strategy to select the optimal orders without needing any a priori information on the target by taking advantage of some analytical considerations in a canonical case.

We developed a data-driven method for target detection in nonstationary environments [J4]. In our method, we employed drift detection algorithms to detect changes in the environment. We used incremental learning, particularly learning under concept drift algorithms, to learn the new statistical characteristics of the environment, which are then utilized to intelligibly update the statistical detection algorithms. We showed that our method can significantly improve the detection performance compared with detection techniques that are not aware of the environmental changes.

We developed a method for joint design of amplitudes and frequency-hopping codes for frequency-hopping waveforms using a colocated multiple input/multiple output (MIMO) radar system [J3]. We formulated the problem based on sparse recovery and the ambiguity function of the MIMO radar system for frequency-hopping waveforms. We proposed two strategies for amplitude design: amplitude design with separate constraints and amplitude design by fusing all transmitters. We formulated a novel game theory based model and propose two joint design algorithms, one applying a noncooperative scheme and the other applying a cooperative scheme. We demonstrated that the joint design method yields better combined code and amplitude matrices that result in improved performance over that of separate designs.

We investigated the effect of multiple scattering in the detection and estimation of scatterers in signal processing research [C2]. We considered a system of two point scatterers under a general multistatic configuration with multiple transmitters and multiple receivers. We analytically compared the Fisher information matrices when multiple scattering either exists or does not. We showed that when the two scatterers are in far-field locations and well-resolved, multiple scattering is favorable for the estimation.

We considered the problem of direction of arrival (DOA) estimation based on a nonuniform linear nested array in the presence of model errors [J1]. We investigated the self-calibration problem for perturbed nested arrays, and proposed corresponding robust algorithms to estimate both the model errors and the DOAs. We exploited the partial Toeplitz structure of the
covariance matrix to estimate the gain errors, and used the sparse total least squares to deal with the phase error issue. In addition, we provided the Cramér-Rao bound (CRB) to analyze the robustness of the estimation performance of the proposed approaches.

We considered the problem of adaptive Gaussian mixture learning in posterior-based distributed particle filtering, in which posteriors are approximated as Gaussian mixtures for wireless communication [J9, C1]. We developed a hierarchical clustering algorithm based on adaptive splitting, whose result is used as an initial guess for the expectation-maximization algorithm to obtain a local maximum likelihood solution. We showed that our method can provide higher accuracy with reduced the computation and communication cost in distributed particle filtering.

We developed algorithms to compute the performance bounds on convex block-sparsity recovery using fixed point theory and semidefinite programming [J5]. These computable performance bounds would open doors for wide applications in sensor arrays, radar, DNA microarrays, etc. We defined a family of quality measures such that the reconstruction errors of convex recovery algorithms are bounded in terms of these quality measures. We associate the quality measures with the fixed points of functions defined by a series of semidefinite programs, yielding polynomial-time algorithms with global convergence guarantees to compute these quality measures. We demonstrated that as long as the number of measurements is relatively large, these quality measures are bounded away from zero for a large class of random sensing matrices, a result parallel to the probabilistic analysis of the block restricted isometry property.

Recently, we also considered the problem of low-dimensional-model-based electromagnetic imaging [J12]. We developed target detection methods using weather radars and electromagnetic vector sensors [J13]. We investigated a new antenna structure named random frequency diverse arrays in active sensing [J7]. We analyzed the asymptotic DOA estimation performance of sparse linear arrays, such as co-prime and nested arrays, and derived the CRB [J8]. We derived the maximum-likelihood estimator (MLE) and the CRB for inertial sensor arrays [J6]. We developed a hypothesis testing framework based on the $\beta$-model and derived the corresponding MLE and CRB [J10]. We proposed a model for decision making under the influence of an artificial social network [J11].

2 Annual Archival Publications:

2.1 Journal Papers


2.2 Conference Papers


3 Awards and Honors

1. Jichuan Li (PhD student), was selected the NSF travel award for Sixth IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), Cancún, Mexico, Oct. 2015.

4 Dissertations


5 Relevant Placements of PhD Graduates

1. Jichuan Li (PhD, 2015) is a Software Engineer, Google Inc., Mountain View, California.
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Principal Investigator Name
The full name of the principal investigator on the grant or contract.
Dr. Arye Nehorai

Program Officer
The AFOSR Program Officer currently assigned to the award
Dr. Arje Nachman

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08/01/2011

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Abstract
We developed a new algorithm for sparse imaging of perfect electric conducting targets based on higher order sources or multipoles. We devised a strategy to select the optimal orders without needing any a priori information on the target by taking advantage of some analytical considerations in a canonical case. We developed a data-driven method for target detection in nonstationary environments. We employed drift detection algorithms to detect changes in the environment, which are utilized to intelligibly update the statistical detection algorithms to gain improved detection performance. We developed a method for joint design of amplitudes and frequency-hopping codes for frequency-hopping waveforms using a colocated multiple input/multiple output radar system. We formulated a novel game theory based model and propose two joint design algorithms. We considered a system of two point scatterers under a general multistatic configuration and investigated the effect of multiple scattering in the detection and estimation of scatterers. We investigated the self-calibration problem for perturbed nested arrays in the presence of gain and phase errors, and developed robust algorithms to estimate the direction-of-arrivals (DOAs). We developed an adaptive Gaussian mixture learning algorithm in posterior-based distributed particle filtering, in which posteriors are approximated as Gaussian mixtures for wireless communication. We developed polynomial-
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**Archival Publications (published) during reporting period:**

**Book Chapters:**


**Journal Papers:**


34. J. Li and A. Nehorai, “Distributed particle filtering via optimal fusion of Gaussian mixtures,” in revision for IEEE Trans. on Signal and Information Processing over Networks.


Conference Papers:


3. P. Yang, G. Tang and A. Nehorai, “Sparsity enforced regression based on over-complete dictionary,” in Proc. 4th Intl. Workshop on Computational Advances in Multi-Sensor


18. K. Han and A. Nehorai, "Joint frequency-hopping waveform design for MIMO radar estimation using


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Dr. Arje Nachman

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None

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

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