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GUEST EDITORIAL

Array signal processing and systems

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We are delighted to present this special issue of Multidimensional Systems and Signal Processing on Array Signal Processing and Systems. Sensor arrays play an important role in spatio-temporal signal processing with applications spanning across multiple fields such as electromagnetic, acoustics, ultrasonic and seismic processing systems. This plethora of possible applications has sparked a large number of new theoretical developments and array processing systems in the last few years.

In the field of electromagnetic sensor (antenna) arrays, there is much interest in the electronically-steerable radio-frequency (RF) beams that can be obtained from phased-array antennas. In the microwave bands, phased-array antennas take both analog and digital signal processing approaches, and find applications in wireless base-stations, radar sensors, space communications, and radio telescopes. In the emerging mm-wave regime, modern applications of array processing are of paramount importance for wireless communications. In particular, emerging 5G systems based on massive-MIMO basestations depend on array processing to mitigate the effects of high path loss and blockages in an urban environment. Acoustic sensor (microphone) arrays are extremely useful for audio and multimedia applications, including high-fidelity sound recording, immersive multimedia and augmented/virtual reality. Ultrasound sensor arrays find extensive applications in biomedical engineering where they are used for imaging the human body and in structural health monitoring of airframes

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and other structures in harsh environments. This Special Issue aims to present recent important developments of array signal processing and systems. Both original research articles and review articles in relevant fields are covered.

Following an open call for papers, seventeen articles are included in this Special Issue. More precisely, the Special Issue includes one review article and sixteen research articles. In the review article by Romanofsky and Toonen (2016), a brief history of developments which led to the realization of array antennas based on ferroelectric thin films is presented and key performance differences provided by competing thin film deposition techniques are highlighted. Moreover, the authors discuss the outlook of the impact that voltage-controlled magnetism and magnetoelasticity (provided by emerging multiferroic thin films) will have on future array antenna technologies.

The remaining 16 articles can be generally grouped into three thematic areas: (1) parameter estimation using sensor arrays; (2) beamforming for sensor arrays, and (3) signal processing in phased-array and multiple-input multiple-output (MIMO) radars as detailed below.

1 Parameter estimation using sensor arrays

In this group, we have 9 papers, which mainly focus on the estimation of direction-of-arrival (DOA) and frequency. The paper by Liu et al. (2016) presented an algorithm for two-dimensional DOA estimation of noncircular sources using an L-shaped sparse array composed of two co-prime arrays. In this method, the array aperture can be significantly increased, while the computational complexity is still acceptable since the azimuth angles can be estimated without peak searching and eigenvalue decomposition. Simulation results show that this method can provide improved performance in terms of the estimation accuracy and resolution.

Ali Khan et al. (2016) proposed a novel DOA estimation algorithm that uses the adaptive directional t–f distribution (ADTFD) for the analysis of close signal components. This algorithm optimizes the direction of kernel at each point in the t–f domain to obtain a clear t–f representation, which is then exploited for DOA estimation. Experimental results indicate the use of adaptive directional TFD outperforms other TFDs in terms of resolution and cross-term suppression properties. This method also gives good results for sparse signals.

In the paper by Zhang et al. (2017), a new method is presented to effectively estimate the signal DOA and the phase error of a uniform linear array. Assuming that one sensor has been calibrated, this method appropriately reconstructs the data matrix and establishes a series of linear equations with respect to the unknown parameters through eigenvalue decomposition. The unknown parameters can be determined directly by the least squares method. Unlike the conventional methods, the proposed method only requires one calibrated sensor, which may not be consecutively spaced to the reference one. The computational complexity analysis is given and the effectiveness of the proposed method is validated by simulation results.

In the paper by Li et al. (2016a), a new DOA estimation method is proposed using a rotational uniform linear array (RULA) consisting of omnidirectional sensors. The main contribution of this method is that the number of distinguishable signals is larger than the methods in the literature with a uniform linear array consisting of the same number of omnidirectional sensors. Moreover, the new method can effectively reduce unknown spatial noises using a generalized complement projection matrix under the RULA framework. Extensive simulations demonstrate that the performance of RULA is satisfactory under various circumstances.

The paper by Astapov et al. (2017) discussed the problem of distinguishing gunshot Shockwave (SW) and Muzzle Blast (MB) gunshot events in a scenario with presence of NOI acoustic events, where the MB transient is not guaranteed to strictly follow the SW transient. A shooter localization procedure comprising gunshot acoustic event identification based on DOA information, gunshot geometry estimation and shooter position estimation was presented and verified on real-life data. The main advantages of the proposed localization procedure include its ability to operate asynchronously in a size-invariant WSN, low dependency on gunshot parameter assumptions and increased noise tolerance.

The paper by Wu et al. (2016) conducted an explicit theoretical analysis of the characteristics of the phase difference between any two array elements in spatially separated electromagnetic vector sensor array (SS-EVSA). Theoretical formulas describing the phase difference between array elements are derived from the phase descriptor and the geometric descriptor. Based on the characteristics of the phase difference, a new half-interval search MUSIC (HIS-MUSIC) algorithm is proposed. By searching half of the four-dimensional space, a joint estimation of the direction of arrival and polarization of the incident signal is obtained, which can effectively reduce the computational complexity of the joint estimation of the four-dimensional space. Finally, the efficiency of the algorithm is demonstrated by simulation experiments.

The paper by Li et al. (2017) proposed a novel algorithm for estimating the motion parameters of air maneuvering target by means of reconstructing time samples and signal. In this method, the received data of multiple antennas are first spliced together to reconstruct time samples of a single antenna by compensating a proper phase. Next, an ideal signal whose time sample number is equal to the length of the reconstructed time samples is constructed. At last, the estimation results of initial velocity and acceleration of the air maneuvering target are obtained by applying the nonlinear least squares method to compare the similarity between the reconstructed time samples and signal. This algorithm can achieve accurate parameter estimation with limited pulses.

The paper by Anil Kumar et al. (2016) considered the problem of spectrum blind reconstruction (SBR) and DOA estimation of constituent sources of a disjoint multi-band signal (MBS) at sub-Nyquist sampling rates. A simple modification to the receiver architecture by introducing an additional delay channel at every sensor is devised. Estimation algorithms based on ESPRIT is then employed to estimate the carrier frequencies, while MUSIC algorithm is employed to estimate their corresponding DOAs. With these parameters, the MBS spectrum is then reconstructed. A two-dimensional iterative grid refinement algorithm is also described to further improve the estimation accuracy. Identifiability issues are addressed and the conditions for unique identifiability are discussed. Numerical simulations are presented to show the validity of the proposed approach and compare the performance against appropriate bounds.

The paper by Amanat et al. (2017) addressed the problem of two-dimensional autoregressive estimation in the presence of additive white noise. The estimation method is developed by combining the low-order and high-order Yule-Walker (YW) equations. The noise-compensated YW equations are solved using an iterative algorithm. The proposed method is also applied to joint frequency and direction of arrival estimation in uniform linear arrays. It is shown by simulations that the performance of the proposed algorithm is evaluated and compared with other methods.

2 Beamforming for sensor arrays

In this group, we have 2 papers. The paper by Wang et al. (2016) presented an enhanced eigenspace-based beamformer (ESB) by using the minimum sensitivity criterion. The proposed beamformer has significantly improved robustness against steering vector errors. The sensitivity function is defined as the squared norm of the appropriately scaled weight vector and since the sensitivity function of an array to perturbations becomes very large in the presence of steering vector errors, it can be used to find the best projection for the ESB, irrespective of the distribution of additive noises. As demonstrated by simulation results, the proposed beamformer has a better performance than the classic ESBs and the previously proposed uncertainty set based approach.

The paper by Ariyarathna et al. (2016) explored methods for synthesizing approximately frequency independent array factors at lower hardware complexity for wideband beamforming applications. The proposed approach employs 2-D infinite impulse response (IIR) digital beam filters together with nested uniform linear arrays (ULAs). The array is designed to have multiple levels of nesting. Each level of nesting consists of a ULA covering a temporal subband of the incident wideband signal. The use of nested arrays provides the required aperture size using a smaller number of elements compared to using a single ULA to capture the entire wideband signal. The use of different levels of nesting allows the operation of the digital processor for each sub-band at different clock rates. This is a hierarchical approach that saves both digital VLSI hardware and power consumption. The 2-D IIR digital beam filters that process each subband signal from each of the nested subarray achieves wideband beamforming. Simulations illustrate approximately frequency independent passbands as required in wideband beamforming.

3 Signal processing in phased-array radar and MIMO radar

In this group, we have 5 papers. The paper by Li et al. (2016b) proposed a novel wind speed estimation algorithm with airborne phased array weather radar for low altitude wind-shear, by combining space time adaptive processing and compressive sensing (CS). Thanks to the use of compressive sensing, the proposed method is able to estimate the wind speed accurately even with limited number of sampling pulses. The performance of the proposed algorithm is verified with numerical simulations.

In the paper by Liu and Wang (2016), a reweighted L_1 norm penalty algorithm for MMV problem in monostatic MIMO radar is proposed. The SVD technique is utilized to reduce the computational complexity and the sensitivity to noise. Then, a constrained minimization problem is formulated, and the coefficients of the RD-Capon spatial spectrum are exploited to design a weight matrix for reweighting L_1 norm penalty minimization. Finally, the DOAs can be obtained by solving the reweighted L_1 norm constraint minimization. Simulation results illustrate that this algorithm can provide better angle estimation performance than RD-Capon and L_1-SRACV algorithms.

In the paper by Hu et al. (2017), high resolution three-dimensional (3D) imaging method using MIMO radar with sparse array is studied. A method based on CS is firstly given. However, the CS-based method has the off-grid problem which will reduce the estimation accuracy of scatterers' position. Moreover, a high dimensional measurement matrix is required in the CS-based method, which will lead to a heavy storage and computation burden. To this end, a new method based on matrix completion is proposed. After reshaping the sparse 3D echo into a low-rank structured matrix, the full 3D echo can be recovered by solving a nuclear norm minimization problem. Then the accurate position of scatterers can be estimated by applying multi-dimensional harmonic retrieval methods to the full 3D echo. Finally, the high resolution 3D image of targets is reconstructed. The effectiveness of the method is validated by the results of comparative simulations.

In the paper by Shahbazi et al. (2017), a measurement matrix for CS-MIMO radar in the presence of clutter and interference is designed. To optimize the measurement matrix, three main criteria are considered simultaneously to improve detection and sparse recovery performance while suppressing clutter and interference. Due to the use of simultaneous multi-objective functions, a multi-objective optimization (MOO) framework is exploited. Some numerical examples are provided to illustrate the achieved improvement of our proposed method in target detection and sparse recovery performance. It is shown that the proposed MOO technique for measurement matrix design can achieve superior performance in target detection compared with Gaussian random measurement matrix technique.

In the paper by Fang et al. (2016), two nested algorithms, nested-ESPRIT and nested-ML, for joint DOD and DOA estimation in bistatic MIMO radar are proposed. The essence of the nested algorithms is to amalgamate signal grouping schemes with DOD/DOA estimation so that DODs and DOAs are iteratively and precisely estimated using only 1-D ESPRIT or 1-D MLE. Additionally, the estimated DODs and DOAs are automatically paired together without any overhead. Simulation results illustrate the superiority of the new algorithms in terms of the tradeoff between estimation accuracy and complexity.

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