Abstract

Direction-of-arrival (DOA) estimation is a problem of great interest to the researchers working in sensors array signal processing due to its wide range of applications, e.g., radar, sonar, bio-medical source localization, geo-localization, radio astronomy, wireless communications, surveillance, emergency rescue, etc. The conventional DOA estimation methods, e.g. delay and sum beamformer (DSB), Capon beamformer, multiple signal classification (MUSIC), estimation of Parameters by Rotational Invariant Techniques (ESPRIT), etc., offered the degree-of-freedom (DOF) equal to the number of sensors, M, and hence suffered from processing only upto $M-1$ sources, limited resolution, and limited estimation accuracy. To overcome the above-mentioned limitations, this thesis proposes several signal processing algorithms for DOA estimation using higher-order statistics (HOS), including unconventional higher-odd-order cumulants.

To begin with, a $(2q+1)-$MUSIC algorithm is proposed for DOA estimation of non-Gaussian sources by exploiting higher odd-order statistics, namely $(2q+1)^{\text{th}}$-order cumulants ($(2q+1)-$OC) of the received data, where q is a positive integer. We analyze different arrangements of the above-mentioned cumulant values into a rectangular matrix to develop an optimal arrangement that maximizes the number of identifiable sources by the proposed $(2q+1)-$MUSIC. Compared with the $2q-$MUSIC, the proposed $(2q+1)-$MUSIC can process the same maximum number of sources, $\mathcal{O}\left(M^q\right)$ but with improved angular resolution and enhanced DOA estimation accuracy. However, the angular resolution and estimation accuracy are not attained their optimum values in the proposed $(2q+1)-$MUSIC due to the loss of the differential information by matricizing the cumulants tensor.

In addition, another DOA estimation algorithm, namely $Q^{\text{th}}-$order cumulants-

based tensor MUSIC ($Q-$TMUSIC), is proposed in this thesis by exploiting the $Q^{\text{th}}-$order cumulants ($Q-$OC) tensor directly by using multi-linear singular value decomposition, where $Q \in \{2, 3, 4, \cdots\}$. Due to the strong orthogonality with $Q-$way tensors, the proposed $Q-$TMUSIC offers significantly improved DOA estimation performance in terms of angular resolution and estimation accuracy compared to their equivalent matrix based $Q-$MUSIC. However, the major price paid by the proposed $Q-$TMUSIC lies in terms of its relatively lower identifiability of $(M-1)$ sources using an array of $M-$sensors than that of $\left(M^{\left\lfloor \frac{Q}{2} \right\rfloor} - 1\right)$ with $Q-$MUSIC.

Furthermore, this thesis presents a mathematical framework to devise a third-order exhaustive co-array (TO-ECA) signal model by vectorizing the array data's third-order cumulants ($3-$OC). Subsequently, a novel sparse linear array (SLA) geometry, namely the third-order nested array (TONA), is proposed by maximizing the virtual uniform linear array (VULA) aperture of the TO-ECA to enhance the identifiability of the given sensors array significantly.

Moreover, this thesis presents a $2q^{\text{th}}$-order circular cumulants ($2q-$OCC) based virtual array signal processing to enhance the DOF of a single Acoustic Vector Sensor (AVS), where $q \in \{1, 2, 3, \cdots\}$. The enhanced DOF of a single AVS increases its maximum sources' resolvability, improves the angular resolution, and enhances the estimation accuracy of the given two-dimensional (2-D) DOAs. The maximum number of the identifiable 2-D DOAs by the AVS is found to be 3, 8, and 14 for the order of cumulants 2, 4, and 6, respectively, provided all the sources' elevations and azimuths are different. Furthermore, the maximum number of the identifiable 2-D DOAs by the AVS is found to be 2, 4, and 6 for the order of cumulants 2, 4, and 6, respectively, provided all the sources have the same elevation (or azimuth) with different azimuths (or elevations). However, the cost of the aforementioned performance gains mainly lies in the requirement of relatively more data, as the HOS-based estimates involve a relatively larger variance compared to the conventional second-order statistics (SOS) based estimates.