論 文 内 容 の 要 旨

Recent year have seen rapidly increasing demand for services and systems that depend upon accurate positioning of people and machines. This has led to the development and evolution of numerous positioning systems. In addition to these systems, direction-of-arrival (DOA) estimation in particular plays a critical role in navigation systems for the exploration of sources in widespread applications, such as voice activity detection, human computer interaction, automatic camera steering, robotics and surveillance. Although wide variety of DOA estimation methods have been proposed for the multitude of applications, DOA estimation for acoustic sources however has not been widely investigated, and many significant methods cannot be applied to acoustic circumstances directly. The reason is that the most of DOA estimations are based on wireless communications and characteristics of wireless signal are totally different from the acoustic signal. Furthermore, the presence of reverberation and background noise present challenges that need to be addressed in a realistic environment.

This dissertation therefore aims to bridge a research gap of acoustic source compatibility on recent DOA estimation methods for estimating DOA of the acoustic sources directly and effectively. Our research works focus on the development of new frameworks, suitable theories and extended techniques for estimating acoustic DOAs in the hope of improving efficacy, simplicity, and yet accuracy, to solve practical problem.

Since the conventional signal modeling techniques solely focus on a narrowband signal, which is necessary to consider an acoustic source or equivalence to wideband source for more practical use, especially in case of human speech. Therefore, the first research work of this dissertation begins with an alternative signal modeling for acoustic sources with L-shaped microphone array configuration. The problem of estimating acoustic DOAs is addressed and resolved by declaring terms of temporal and reference frequencies in array manifold matrices of the signal model. In addition to this, the proposed model is now compatible with almost recent narrowband DOA estimation methods, it means that this model enables cutting-edge techniques in the existing narrowband subspace methods to apply acoustic source directly and efficiently.

After the acoustic signal modeling technique has been successfully given, we continue to present DOA estimation method for acoustic sources by using unsupervised learning along with this signal model. The problem of estimating DOA of acoustic signals is addressed by focusing the entire observation subspace in each frequency bin. In addition to this observation process, we employ the Gaussian mixture model with a maximum likelihood estimation algorithm as an interpolation scheme, and the DOA results are estimated easily by interpolating the multi-narrowband DOA results all frequency bins with this interpolation scheme. The performance is evaluated in terms of root-mean-square-error over a range of signal-to-noise ratio (SNR), and the results suggest that the proposed method is a particularly effective method of DOA estimation with a requirement of high computational resources.

Intensive computational costs encountered in the previous work may be limited by practical considerations when it comes to two-dimensional (2D) wideband or acoustic DOA estimation, in the next section, we propose a computationally efficient 2D wideband DOA estimation method. We provide new properties of wideband signal subspace orthogonality to reduce a computational complexity of 2D DOA algorithm. Numerical simulations show that the performance of new method can be especially effective, and the computational complexity is significantly lower than many existing methods, making it suitable for embedded systems and real-time applications.

In the next part of work, we present an efficient wideband or acoustic 2D DOA estimation, which is an improved version of the previous method. We propose a way to construct a wideband sample cross-correlation matrix without any process of DOA preliminary estimation, such as beamforming technique, by exploiting sample cross-correlation matrices of two different frequencies for all frequency bins along with the Orthogonal Procrustes analysis. Subsequently, wideband DOAs are estimated by using this wideband matrix along with a recent scheme of estimating DOA in a narrowband subspace method. A contribution of this work is providing an alternative framework for recent narrowband subspace methods to estimating the DOA of wideband sources directly. It means that this framework enables cutting-edge techniques in the existing narrowband subspace methods to implement the wideband direction estimation for reducing the computational complexity and facilitating the estimation algorithm. Theoretical analysis and effectiveness of the proposed method are substantiated through numerical simulations, and the results show that performance of the proposed method performs better than others over a range of SNR with just a few microphones.

In addition to Orthogonal Procrustes analysis as used in the previous work, in the next part of work, we improve accuracy performance of the previous framework for estimating wideband or acoustic DOA by proposing an extension theory of Orthogonal Procrustes analysis with much more efficiently than the original theory. The proposed framework is inspired by the coherent signal subspace technique with further improvement of linear transformation procedure, and the new procedure no longer require any process of DOA preliminary estimation by exploiting unique cross-correlation matrices between received signal and itself on distinct frequencies, along with the higher-order generalized singular value decomposition of the array of this unique matrix. Wideband DOAs are estimated by employing any subspace-based technique for estimating narrowband DOAs, but using the proposed wideband correlation instead of a conventional narrowband correlation matrix. It implies that the proposed framework enables cutting-edge researches in the recent narrowband subspace methods to estimate DOA of the wideband sources directly, which result in the reducing computational complexity and facilitating the estimation algorithm. This thus be a major contribution of the proposed framework as same as the previous framework, but much more efficiently than the previously. Practical examples are presented to showcase its applicability and effectiveness, and the experimental results show that the performance of fusion methods perform better than others over a range of SNR with just a few sensors, which make it suitable for practical use.

In the next stage of our work, we investigate an alternative but highly efficient way to construct a wideband cross-correlation matrix in the wideband subspace method by using all samples from both identical and distinct domains of frequencies instead of the fixed domain as done in the previous work. To avoid computational burden caused by intensive use the sample from all domains, an optimized mathematical model of received signal for all frequency is given and derived without loss of generality. Numerical simulations show that the performance of proposed cross-correlation matrix can be especially effective over range with a more favorable SNR.

Unlike all previous methods that have focused on estimating wideband or acoustic DOAs, the final part of this work addresses a problem to estimate a variance of sources for all frequency bins and its DOAs simultaneously. Signal model is renovated into a tensor representation of the three features: x-subarray angle, variance-of-frequencies, and z-subarray manifold angle. In particular, complex-valued parallel factor analysis is used as the tensor factorization, and the variance-of-frequencies and its DOAs are now estimated simultaneously via this factorization technique. Effectiveness of proposed method is substantiated through numerical simulations, and it suggests that our method provides a promising alternative for intelligent source localization.

In the end, we believe that our research findings presented in this dissertation will appeal to researchers who wish to develop a sound source based navigation system and improve its robust estimation. We also hope that these findings can be a good alternative for estimating DOA of acoustic sources, especially human speeches and musical sounds.