UNIVERSITY OF THE WITWATERSRAND

Abstract

Engineering and the Built Environment
School of Electrical and Information Engineering

Master of Science in Engineering

A Study of Toeplitz Decorrelation Techniques for Direction of Arrival Estimation of Coherent Sources

by Frans Shiwovanhu SHAFUDA

Supervisor(s): Prof. Anton VAN WYK, Mr. Andre MCDONALD and Prof. Jaco VERSFELD

The Direction of Arrival (DOA) is one of the features of propagating waves that is of interest in sensor array signal processing. Applications such as direction finding and source location make use of DOA estimation. A number of DOA estimation methods have been developed over time with special focus on achieving high resolution performance. Subspace-based, also known as eigenstructure-based; methods such as Multiple Signal Classification (MUSIC) and Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) are amongst the excellent and widely applied methods for DOA estimation. However, the performance of these methods is highly degraded in the presence of coherent or highly correlated incident sources caused by multipath propagation and electronic jamming. Conventional techniques such as spatial smoothing have been introduced to better the performance of these methods by removing correlation between coherent sources. However, this is attained at the expense of reduced array aperture (degree of freedom) and increased computational complexity. Of late, a variation of decorrelation techniques based on Toeplitz matrix theory gained much interest in overcoming the drawbacks of conventional decorrelation techniques. Based on a narrowband signal propagation model and a Uniform Linear Array (ULA) in the presence of white additive Gaussian noise, this study carried out an algebraic analysis of two Toeplitz decorrelation techniques. These are, the correlation Toeplitz (CTOP) and the average Toeplitz (AVTOP) decorrelation techniques. The techniques were studied for DOA estimation of coherent sources in conjunction with the MUSIC algorithm. The goal of the study is to provide an understanding of how and why these techniques work. Through the algebraic analysis the study found that, DOA information is perfectly preserved during decorrelation when retained as sums of individual sources of information (i.e. in a superposition form). This explains why the CTOP technique perfectly decorrelates coherent sources unlike the AVTOP technique. This is because decorrelation based on the CTOP technique retains superimposed sources' DOA information. Based on the assumption that the exact signal plus noise array covariance matrix is known, the MUSIC algorithm was applied algebraically in order to validate the findings from the analysis. A maximum of four array elements and three coherent narrowband sources were considered. The algebra becomes intractable when the ULA elements are more than four. The algebraic results have further shown that when the exact array covariance matrix is known, the noise variance has no influence on DOA information and DOA information can be accurately obtained using the MUSIC algorithm. Numerical simulations were also conducted in order to confirm the superiority of the CTOP decorrelation technique. Through numerical experiments, the performance of these techniques was evaluated in terms of Root Mean Square Error, standard deviation and probability of success in DOA estimation. The performance of the classic MUSIC algorithm was also evaluated to serve as a baseline for comparison. Regardless of the coherence among the sources, the CTOP MUSIC (CTOP technique applied in conjunction with the MUSIC algorithm) returns more accurate estimates even at low levels of SNR and minimum number of array sensors. The study has been able to provide an understanding of the working principles behind the two Toeplitz decorrelation techniques.