(Revised 07/09)

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NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Advanced Signal Processing for Target Enumeration and Localization in Multiple-Input Multiple-Output Radar

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Dr. Hing Cheung So	Prof. Lei Huang
Post	Associate Professor	Chair Professor
Unit / Department / Institution	Department of Electronic Engineering, City University of Hong Kong	College of Information Engineering, Shenzhen University
Co-investigator(s) *(with title)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1 Jan. 2012		1 Nov. 2011
Project Completion date	31 Dec. 2014		
Duration *(in month)*	36		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. *Develop robust source enumeration algorithms particularly for small number of temporal snapshots.*
2. *Devise accurate and computationally efficient methods for direction-of-departure and direction-of-arrival estimation of multiple targets.*
3. *Extend the developed methodology to joint source enumeration and target localization.*
4. *Evaluate the devised algorithms by comparing with the state-of-the-art schemes in terms of identifiability, robustness, estimation accuracy, threshold performance, computational complexity and spatial resolution for various MIMO radar signal models.*

5.2 Revised Objectives

Date of approval from the RGC: N.A.

(Revised 07/09)

Reasons for the change: _____

_____

1.
2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Regarding target enumeration, we have devised a multi-dimensional version of the ESTER algorithm with the use of tensor algebra [J1], for tackling colored noise environments. We also propose the CORCONDIA with adaptive threshold [C1] to achieve accurate source number estimation in multi-dimensional data at both high and low SNRs. Furthermore, we develop the LS-MDL criterion [J5] and shrinkage coefficient based detectors [J16] for reliable source enumeration particularly for small number of snapshots.

Regarding target localization, we have developed improved versions of ESPRIT [J6], [J13],[J19],[C2], MUSIC [J3],[J7],[J14] and multi-dimensional folding [J2]. Our developed solution can provide higher estimation accuracy [J2], [J7], [C2], smaller computational complexity [J6], and/or robustness to impulsive noise [J3]. In particular, localization techniques for the underdetermined case are proposed in [J13], [J14]. Note that the algorithms in [J14] and [J19] can handle uniform circular arrays and noncircular signal sources, respectively. Furthermore, we have exploited the frequency diverse array radar configuration to improve target localization performance, and the major findings have been published in [J8], [J11].

Joint target enumeration and localization is addressed in [J4], [J10], [J12], [J15]. In [J4], a parametric subspace methodology is devised to identify only the targets with small position errors. The iterative adaptive approach is applied to achieve high-resolution performance in [J10]. While the joint diagonalization structure is utilized for coherent sources in uncorrelated [J12] or correlated [J15] noise environments.

Extensive simulation results show that the proposed solutions have improvements over the state-of-the-art methods in terms of identifiability, robustness, estimation accuracy, threshold performance, computational complexity and/or spatial resolution for different MIMO radar signal models.

As a side product, we have tackled spectrum sensing for cognitive radio, which can be considered as a source enumeration problem, and our findings have been published in [J9], [J17]-[J18], [C3]. MIMO radar waveform design is also studied in [C4].

Potential for further development of the research and the proposed course of action *(maximum half a page)*

In this project, we mainly focus on detecting the number of targets and determining their positions in MIMO radar. Other interesting and important topics in MIMO radar, which include time delay estimation particularly in the presence of multipath propagation, and waveform design, will be our future research works. Utilizing our research findings with appropriate customizations to MIMO sonar systems is also a research direction.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

Radar is an acronym for *ra*dio *d*etection *a*nd *r*anging system. The problems of detecting the number of targets and finding their positions with the use of radar have many important application areas such as military, traffic control, navigation, instrumentation and remote sensing. Multiple-input multiple-output (MIMO) radar is an emerging technology which uses multiple transmitter and receiver antenna arrays to transmit independent waveforms and to receive the reflected signals, and can achieve significant performance improvement over the standard phased-array radar. To advance MIMO radar from concept to reality, however, many research challenges need to be addressed. One key difficulty is to achieve optimum detection and estimation performance particularly when the signal-to-noise ratio is low or the number of snapshots is small. On the other hand, processing of the multi-dimensional MIMO radar signals corresponds to enormous computations and thus algorithm complexity is also a main concern. In this research project, we have developed accurate and computationally attractive algorithms for target enumeration and localization in MIMO radar. We expect that the research results produced will be able to contribute to the advancement of MIMO radar technology, and provide a significant value in the field of array signal processing.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.))

The Latest Status of Publications				Author(s) *(bold the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*					

2013 **[J1]**				**K.Liu*** J.P.C.L.da Costa **H.C.So** **L.Huang**	Subspace based multidimensional model order selection in colored noise, *Signal Processing*, vol.93, no.7, pp.1976-1987, Jul. 2013		Yes	Yes
2013 **[J2]**				**W.Sun** **H.C.So** **F.K.W.Chan** **L.Huang***	Tensor approach for eigenvector-based multi-dimensional harmonic retrieval, *IEEE Transactions on Signal Processing*, vol.61, no.13, pp.3378-3388, Jul. 2013		Yes	Yes
2013 **[J3]**				**W.-J.Zeng** **H.C.So** **L.Huang***	lp-MUSIC: Robust direction-of-arrival estimator for impulsive noise environments, *IEEE Transactions on Signal Processing*, vol.61, no.17, pp.4296-4308, Sep. 2013		Yes	Yes
2013 **[J4]**				**K.Liu** **H.C.So** J.P.C.L.da Costa F.Roemer **L.Huang***	Efficient source enumeration for accurate direction-of-arrival estimation in threshold region, *Digital Signal Processing*, vol.23, no.5, pp.1668-1677, Sep. 2013		Yes	Yes
2013 **[J5]**				**L.Huang*** **H.C.So**	Source enumeration via MDL criterion based on linear shrinkage estimation of noise subspace covariance matrix, *IEEE Transactions on Signal Processing*, vol.61, no.19, pp.4806-4821, Oct. 2013		Yes	Yes

2014 **[J6]**				**C.Qian** **L.Huang*** **H.C.So**	Computationally efficient ESPRIT algorithm for direction-of-arrival estimation based on Nyström method, *Signal Processing*, vol.94, no.1, pp.74-80, Jan. 2014		Yes	Yes
2014 **[J7]**				**C.Qian** **L.Huang*** **H.C.So**	Improved unitary root-MUSIC for DOA estimation based on pseudo-noise resampling, *IEEE Signal Processing Letters*, vol.21, no.2, pp.140-144, Feb. 2014		Yes	Yes
2014 **[J8]**				**W.-Q.Wang*** **H.C.So**	Transmit subaperturing for range-angle estimation in frequency diverse array radar, *IEEE Transactions on Signal Processing*, vol.62, no.8, pp.2000-2011, Apr. 2014		Yes	Yes
2014 **[J9]**				**L.Huang*** **H.C.So** **C.Qian**	Volume-based method for spectrum sensing, *Digital Signal Processing*, vol.28, pp.48–56, May 2014		Yes	Yes
2014 **[J10]**				**W.Sun** **H.C.So** **Y.Chen** **L.-T.Huang** **L.Huang***	Subspace-based iterative adaptive approach for fast two-dimensional spectral estimation, *IEEE Transactions on Signal Processing*, vol.62, no.12, pp.3220-3231, Jun. 2014		Yes	Yes

2014 [J11]				W.-Q.Wang* H.C.So H.Shao	Non-uniform frequency diverse array for range-angle imaging of targets, *IEEE Sensors Journal*, vol.14, no.8, pp.2469-2476, Aug. 2014		Yes	Yes
2014 [J12]				C.Qian L.Huang* W.-J.Zeng H.C.So	Direction-of-arrival estimation for coherent signals without knowledge of source number, *IEEE Sensors Journal*, vol.14, no.9, pp.3267-3273, Sep. 2014		Yes	Yes
2014 [J13]				F.K.W.Chan H.C.So L.Huang* L.-T.Huang	Underdetermined direction-of-departure and direction-of-arrival estimation in bistatic multiple-input multiple-output radar, *Signal Processing*, vol.104, no.11, pp.284-290, Nov. 2014		Yes	Yes
2015 [J14]				M.Cao L.Huang* C.Qian J.Xue H.C.So	Underdetermined DOA estimation of quasi-stationary signals via Khatri-Rao structure for uniform circular array, *Signal Processing*, vol.106, no.1, pp.41-48, Jan. 2015		Yes	Yes
2015 [J15]				C.Qian L.Huang* Y.Xiao H.C.So	Localization of coherent signals without source number knowledge in unknown spatially correlated Gaussian noise, *Signal Processing*, vol.111, no.6, pp.170-178, Jun. 2015		Yes	Yes

2015 **[J16]**	2014			**L.Huang* C.Qian H.C.So J.Fang**	Source enumeration for large array using shrinkage-based detectors with small samples," *IEEE Transactions on Aerospace and Electronic Systems*		Yes	Yes
2015 **[J17]**	2014			**L.Huang*** J.Fang, **K.Liu H.C.So** H.Li	An eigenvalue-moment-ratio approach to blind spectrum sensing for cognitive radio under sample-starving environment, *IEEE Transactions on Vehicular Technology*		Yes	Yes
2015 **[J18]**	2014			**L.Huang* Y.Xiao H.C.So** J.Fang	Accurate performance analysis of Hadamard ratio test for robust spectrum sensing, *IEEE Transactions on Wireless Communications*		Yes	Yes
2015 **[J19]**	2014			**Y.Shi L.Huang* C.Qian H.C.So**	Direction-of-arrival estimation for noncircular sources via structured least squares-based ESPRIT using 3-axis crossed array, *IEEE Transactions on Aerospace and Electronic Systems*		Yes	Yes

9. Recognized International conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*

May 2013, Vancouver, Canada [C1]	Core consistency diagnostic aided by reconstruction error for accurate enumeration of the number of components in PARAFAC models	International Conference on Acoustics, Speech, and Signal Processing		Yes	Yes
May 2014, Florence, Italy [C2]	Joint angle and frequency estimation using structured least squares	International Conference on Acoustics, Speech, and Signal Processing		Yes	Yes
May 2014, Florence, Italy	Gerschgorin disk-based robust spectrum sensing for cognitive radio	International Conference on Acoustics, Speech, and Signal Processing		Yes	Yes
May 2014, Florence, Italy [C3]	Low peak-to-average ratio OFDM chirp waveform diversity design	International Conference on Acoustics, Speech, and Signal Processing		Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Weize Sun	Ph.D.	Sep. 2009	Aug. 2013
Kefei Liu	Ph.D.	Sep. 2010	Aug. 2013

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

During this research, we also have the opportunities to collaborate with Prof. João Paulo C. Lustosa da Costa at Universidade de Brasília (UnB), Brazil, and Prof. Hongbin Li at Stevens Institute of Technology, USA.