



---

Robust Modulo Remaindering and Applications in Radar and Sensor Signal **Processing**

Xiang-Gen Xia  
UNIVERSITY OF DELAWARE

---

08/27/2015  
Final Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory  
AF Office Of Scientific Research (AFOSR)/ RTC  
Arlington, Virginia 22203  
Air Force Materiel Command

# REPORT DOCUMENTATION PAGE

*Form Approved*  
**OMB No. 0704-0188**

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> 20-08-2015		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> 15-03-2012 - 14-06-2015	
<b>4. TITLE AND SUBTITLE</b>  Robust Modulo Remaindering and Applications in Radar and Sensor Signal Processing				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b> FA9550-12-1-0055	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b> Xiang-Gen Xia				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Department of Electrical and Computer Engineering University of Delaware Newark, DE 19716				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  UODECE SF298REPORT 1-8-15	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Air Force Office of Scientific Research (AFOSR)				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> AFOSR	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b>  Approved for Public Release					
<b>13. SUPPLEMENTARY NOTES</b> N/A					
<b>14. ABSTRACT</b>  This report describes the main research achievements during the time period cited above on the research project in the area of digital signal processing. The main achievements include robust reconstruction of large integers (one or two simultaneous integers) from their remainders/residues modulo several moduli, and the maximal dynamic range for the determinable integers of two from their remainders modulo a set of moduli. It includes their applications in phase un-wrapping in SAR imaging of moving objects, high frequency determination from multiple undersampled signals with very low sampling rates of sensors, and error correction coding. This report also includes a new OFDM SAR imaging by using sufficient cyclic prefix (CP) at transmitter and a non-matched filter imaging algorithm at receiver called inter-range-cell interference (IRCI) free range reconstruction.					
<b>15. SUBJECT TERMS</b> Robust Chinese remainder theorem, generalized Chinese remainder theorem, undersampling, SAR imaging, phase unwrapping, OFDM SAR, MIMO-OFDM SAR					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>  U	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b> Xiang-Gen Xia
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified			<b>19b. TELEPHONE NUMBER (include area code)</b> 302-831-8038

**Standard Form 298 (Rev. 8-98)**  
Prescribed by ANSI Std. Z39.18

Contract/Grant Title: Robust Modulo Remaindering and Applications in Radar and Sensor Signal Processing

Contract/Grant #: FA9550-12-1-0055

Reporting Period: 15 March 2012 to 14 June 2015

Main accomplishments:

To robustly reconstruct a large integer from its several much smaller erroneous remainders modulo a set of moduli, we obtained a robust Chinese remainder theorem (CRT) for a general set of moduli with a new necessary and sufficient condition on the remainder errors, where the moduli after factorizing their greatest common divisor (gcd) may not be necessarily co-prime. This can be thought of as a single stage robust CRT. We also obtained a two-stage robust CRT by grouping the moduli into several groups as follows. First, the single stage robust CRT is applied to each group. Then, with these robust reconstructions from all the groups, the single stage robust CRT is applied again across the groups. Interestingly, with this two-stage robust CRT, the robust reconstruction holds even when the remainder error level is above the quarter of the gcd of all the moduli that is state of the art bound for the single stage robust CRT. Therefore, the two-stage robust CRT further improves the robustness of the single stage CRT. General multi-stage CRT was also proposed. This newly obtained robust CRT has been applied in range estimation in sensor networking etc. We also obtained space-time Radon-Fourier transforms for radar target detection.

We obtained the maximal determinable range for two integers from its multiple remainders modulo a set of moduli and a new fast determination algorithm for two integers from their multiple remainders. We have also obtained a robust reconstruction algorithm for polynomials from their remainders modulo several moduli polynomials and found its applications in error correction coding. We have obtained robust channel-calibration algorithms for multi-channel in azimuth HRWS SAR imaging, which can better accommodate flight trajectory errors in high resolution and wide swath width SAR imaging. SAR imaging using orthogonal frequency division multiplexing (OFDM) signals has existed for a while by borrowing the OFDM concept from the telecommunications literature, where OFDM signals have been just treated as the conventional radar waveforms and their most important feature of intersymbol interference (ISI) (corresponding to inter-range cell interference free (IRCI)) free has not been utilized. We have obtained a new OFDM SAR imaging including new OFDM signal design and new SAR imaging algorithm so that there is no IRCI and therefore it can achieve a super range resolution in a SAR image. We have also obtained a new sparse reconstruction algorithm in ISAR imaging for rotating targets.

We also obtained a maximum likelihood estimation (MLE) based robust CRT that has a fast algorithm that only needs to search for the solution among  $L$  elements, where  $L$  is the number of remainders and the noisy remainders follow wrapped Gaussian distributions. Then, a necessary and sufficient condition on the remainder errors for the MLE CRT to be robust was obtained. We proposed a new CP based OFDM radar signal design for the IRCI free range reconstruction SAR imaging, where the zero head and tail property is proposed at the first time, in addition to the low peak-to-average power ratio (PAPR) in both the time and the frequency domains. We obtained MIMO-OFDM SAR imaging with sufficient CP. With our obtained MIMO-OFDM radar, it achieves IRCI free range reconstruction, collect the full spatial diversity from all the MIMO antennas, and maintains the same range resolution as that in a single antenna radar with the same total bandwidth. We obtained a new MIMO-OFDM radar using circularly shifted Zadoff-Chu sequences.

Refereed journal publications (published) during the reporting period:

- 1) H. M. Wang, Q. Yin, and X.-G. Xia, Distributed Beamforming for Physical-Layer Security of Two-Way Relay Networks, *IEEE Transactions on Signal Processing*, vol. 60, no. 7, pp. 3532-3545, July 2012.
- 2) W. J. Wang, H. Y. Jiang, X.-G. Xia, P. C. Mu, and Q. Yin, A Wireless Secret Key Generation Method Based on Chinese Remainder Theorem in FDD Systems, *Science China -- Information Sciences*, vol.55, no.7, pp.1605-1616, July 2012.
- 3) Y. Liu, X.-G. Xia, and H. L. Zhang, Distributed Space-Time Coding for Full-Duplex Asynchronous Cooperative Communications, *IEEE Transactions on Wireless Communications*, vol. 11, no. 7, pp. 2680-2688, July 2012.
- 4) C. Zheng, G. Li, X.-G. Xia, and X. Wang, Weighted  $\ell_{2,1}$  Minimisation for High Resolution Range Profile with Stepped Frequency Radar, *IET Electronics Letters*, vol. 48, no. 18, pp. 1155-1156, Aug. 2012.
- 5) Y. Lu, W. Zhang, and X.-G. Xia, On Diversity and Multiplexing Tradeoff of Two-Layer D-BLAST with Group Zero-Forcing Detection, *IEEE Transactions on Communications*, vol. 60, no. 8, pp. 2255-2264, Aug. 2012.
- 6) L.-C. Qian, J. Xu, X.-G. Xia, and W.-F. Sun, Fast Implementation of Generalized Radon-Fourier Transform for Maneuvering Radar Target Detection, *IET Electronics Letters*, vol. 48, no. 22, pp. 1427-1428, Oct. 2012.
- 7) L. Shi, W. Zhang, and X.-G. Xia, On Designs of Full Diversity Space-Time Block Codes for Two-User MIMO Interference Channels, *IEEE Transactions on Wireless Communications*, vol. 11, pp. 4184-4191, Nov. 2012.
- 8) J. Xu, X.-G. Xia, S.-B. Peng, J. Yu, Y.-N. Peng, and L.-C. Qian, Radar Maneuvering Target Motion Estimation Based on Generalized Radon-Fourier Transform, *IEEE Transactions on Signal Processing*, vol. 60, pp. 6190-6201, Dec. 2012.
- 9) J. Xu, J. Yu, Y.-N. Peng, X.-G. Xia, and T. Long, Space-Time Radon-Fourier Transform and Applications in Radar Target Detection, *IET Radar, Sonar & Navigation*, vol. 6, no. 9, pp.846-857, 2012.
- 10) S. X. Zhang, M. D. Xing, X.-G. Xia, L. Zhang, R. Guo, and Z. Bao, Focus improvement of high squint SAR based on azimuth dependence of quadratic range cell migration correction, *IEEE Geoscience and Remote Sensing Letters*, vol. 10, pp. 150-154, Jan. 2013.
- 11) G.-C. Sun, M. D. Xing, X.-G. Xia, Y. Wu, and Z. Bao, Robust Ground Moving Target Imaging Using Deramp-Keystone Processing, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, no. 2, pp. 966-982, Feb. 2013.
- 12) W. Rao, G. Li, X. Wang, and X.-G. Xia, Adaptive Sparse Recovery by Parametric Weighted  $L_1$  Minimization for ISAR Imaging of Uniformly Rotating Targets, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 6, no. 2, pp. 942-952, Apr. 2013.
- 13) G.-C. Sun, M.-D. Xing, X.-G. Xia, J. Yang, Y. Wu, and Z. Bao, A unified focusing algorithm (UFA) for several modes of SAR based on FrFT, " *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, Part II, pp. 3139-3155, May 2013.
- 14) T. Xiong, M.-D. Xing, X.-G. Xia, and Z. Bao, New applications of Omega-K algorithm for SAR data processing using effective wavelength at high squint, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, Part II, pp. 3156-3169, May 2013.

- 15) Y. Wu, G.-C. Sun, X.-G. Xia, M. D. Xing, and Z. Bao, An improved shift-and-correlation (SAC) algorithm based on the range-Keystone transform for Doppler rate estimation, *IEEE Geoscience and Remote Sensing Letters*, vol. 10, no. 4, pp. 741-745, Jul. 2013.
- 16) G.-C. Sun, M. D. Xing, X.-G. Xia, Y. F. Wu, P. P. Huang, Y. R. Wu, and Z. Bao, Multichannel full-aperture azimuth processing for beam steering SAR, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, no. 9, pp.4761-4778, Sept. 2013.
- 17) S. Zhou, M.-D. Xing, X.-G. Xia, L. Zhang, and Z. Bao, An azimuth-dependent phase-gradient autofocus algorithm for airborne/stationary bistatic SAR imagery, *IEEE Geoscience and Remote Sensing Letters*, vol. 10, no. 6, pp.1290-1294, Nov. 2013.
- 18) H.-M. Wang, M. Luo, Q. Yin, and X.-G. Xia, Hybrid Cooperative Beamforming and Jamming for Physical-Layer Security of Two-Way Relay Networks, *IEEE Transactions on Information Forensics & Security*, vol.8, no. 12, pp.2007-2020, Dec. 2013.
- 19) S.-X. Zhang, M.-D. Xing, X.-G. Xia, Y.-Y. Liu, R. Gao, and Z. Bao, A robust channel-calibration algorithm for multi-channel in azimuth HRWS SAR imaging based on local maximum-likelihood weighted minimum entropy, *IEEE Transactions on Image Processing*, vol.22, pp.5294-5305, Dec. 2013.
- 20) Li Xiao and X.-G. Xia, A Generalized Chinese Remainder Theorem for Two Integers, *IEEE Signal Processing Letters*, vol. 21, no. 1, pp. 55-59, Jan. 2014.
- 21) Y.-F. Wu, G.-C. Sun, X.-G. Xia, M.-D. Xing, J. Yang, and Z. Bao, An azimuth frequency non-linear chirp scaling (FNCS) algorithm for TOPS SAR imaging with high squint angle, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 7, no. 1, pp.213-221, Jan. 2014.
- 22) W. Rao, G. Li, Q. Wang, and X.-G. Xia, Comparison of parametric sparse recovery methods for ISAR image formation, *Science China--Information Sciences*, vol. 57, no. 2, 022315:1-022315:12, Feb. 2014.
- 23) B. Yang, W. J. Wang, X.-G. Xia, and Q. Yin, Phase detection based range estimation with a dual-band robust Chinese remainder theorem, *Science China -- Information Sciences*, vol. 57, no. 2, 022302:1-022302:9, Feb. 2014.
- 24) T. Xu and X.-G. Xia, A Diversity Analysis for Distributed Interference Alignment Using the Max-SINR Algorithm, *IEEE Transactions on Information Theory*, vol. 60, no. 3, pp. 1857-1868, Mar. 2014.
- 25) W. Rao, G. Li, X. Wang, and X.-G. Xia, Parametric Sparse Representation Method for ISAR Imaging of Rotating Targets, *IEEE Transactions on on Aerospace and Electronic Systems*, vol. 50, no. 2, pp. 910-919, April 2014.
- 26) L.-C. Qian, J. Xu, X.-G. Xia, W.-F. Sun, T. Long, and Y.-N. Peng, Wideband scaled Radon Fourier transform for high-speed radar target detection, *IET Radar, Sensor, and Navigation*, vol. 8, no. 5, pp. 501-512, 2014.
- 27) S.-X. Zhang, M.-D. Xing, X.-G. Xia, L. Zhang, R. Guo, Y. Liao, and Z. Bao, Multi-Channel HRWS SAR Imaging Based on Range-Variant Channel-Calibration and Multi-Doppler-Direction Restriction Ambiguity Suppression, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, no. 7, pp. 4306-4327, July 2014.
- 28) X. Li, M. Xing, X.-G. Xia, G.-C. Sun, Y. Liang, and Z. Bao, Deramp Space-Time Adaptive Processing for Multichannel SAR Systems, *IEEE Geoscience and Remote Sensing Letters*, vol. 11, no. 8, pp. 1148-1452, Aug. 2014.

- 29) F. Zhou, G.-C. Sun, X.-G. Xia, M.-D. Xing, and Z. Bao, Stepped frequency synthetic preprocessing algorithm for inverse synthetic aperture radar imaging in fast moving target echo model, *IET Radar, Sonar, and Navigation*, vol. 8, no. 8, pp. 864-874, 2014.
- 30) S.-X. Zhang, M.-D. Xing, X.-G. Xia, R. Guo, and Z. Bao, A Novel Moving Target Imaging Algorithm for HRWS SAR Based on Local Maximum-likelihood Minimum Entropy in Range Frequency," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, no. 9, pp. 5333-5348, Sept. 2014.
- 31) T. Zhang, X.-G. Xia, and L. Kong, IRCI Free Range Reconstruction for SAR Imaging with Arbitrary Length OFDM Pulse, *IEEE Trans. on Signal Processing*, vol. 62, no. 18, pp. 4748-4759, Sept. 2014.
- 32) L. Xiao, X.-G. Xia, and W.-J. Wang, Multi-Stage Robust Chinese Remainder Theorem, *IEEE Trans. on Signal Processing*, vol. 62, no. 18, pp. 4772-4785, Sept. 2014.
- 33) J. Yang, G.-C. Sun, M. Xing, X.-G. Xia, Y. Liang, and Z. Bao, Squinted TOPS SAR Imaging Based on Modified Range Migration Algorithm and Spectral Analysis, *IEEE Geoscience and Remote Sensing Letters*, Vol. 11, No. 10, pp. 1707-1711, Oct. 2014.
- 34) T.-X. Zhang and X.-G. Xia, OFDM Synthetic Aperture Radar Imaging with Sufficient Cyclic Prefix, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 53, No. 1, pp. 394-404, Jan. 2015.
- 35) H.-M. Wang, T.-X. Zheng, and X.-G. Xia, Secure MISO Wiretap Channels With Multi-Antenna Passive Eavesdropper: Artificial Noise vs. Artificial Fast Fading, *IEEE Transactions on Wireless Communications*, vol. 14, no. 1, pp. 94-106, Jan. 2015.
- 36) S.-X. Zhang, M.-D. Xing, X.-G. Xia, R. Guo, and Z. Bao, Robust Clutter Suppression and Moving-Target Imaging approach for Multi-channel in Azimuth High-Resolution and Wide-Swath Synthetic Aperture Radar, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 2, pp. 687-709, Feb. 2015.
- 37) W. Wang, X.-P. Li, X.-G. Xia, and W.-J. Wang, The largest dynamic range of a generalized Chinese remainder theorem for two integers, *IEEE Signal Processing Letters*, vol. 22, no. 2, pp. 254-258, Feb. 2015.
- 38) C. Wang, H.-M. Wang, and X.-G. Xia, Hybrid Opportunistic Relaying and Jamming with Power Allocation for Secure Cooperative Networks, *IEEE Transactions on Wireless Communications*, vol. 14, no. 2, pp. 589-605, Feb. 2015.
- 39) L. Xiao and X.-G. Xia, Error Correction in Polynomial Remainder Codes with Non-Pairwise Coprime Moduli and Robust Chinese Remainder Theorem for Polynomials, *IEEE Transactions on Communications*, vol. 63, no. 3, pp.605-616, March 2015.
- 40) G. Xu, M.-D. Xing, X.-G. Xia, L. Zhang, Y.-Y. Liu, and Z. Bao, Sparse Regularization of Interferometric Phase and Amplitude for InSAR Image Formation Based on Bayesian Representation, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 4, pp. 2123-2136, April 2015.
- 41) C. Meng, J. Xu, X.-G. Xia, F. Liu, T. Long, E. Mao, J. Yang, and Y. Peng, MIMO-SAR waveforms separation based on virtual polarization filter, *Science China -- Information Sciences*, vol. 58, no. 4, pp.042301:1--042301:12, April 2015.
- 42) Y.-H. Cao and X.-G. Xia, IRCI free MIMO-OFDM SAR using circularly shifted Zadoff-Chu sequences, *IEEE Geoscience and Remote Sensing Letters*, vol. 12, no. 5, pp.1126-1130, May 2015.

- 43) W.-J. Wang, X.-P. Li, W. Wang, and X.-G. Xia, Maximum Likelihood Estimation Based Robust Chinese Remainder Theorem for Real Numbers and Its Fast Algorithm, *IEEE Transactions on Signal Processing*, vol. 63, no. 13, pp.3317-3330, July 2015.
- 44) P. Shao, M.-D. Xing, X.-G. Xia, Y.-C. Li, X. Li, and Z. Bao, Autofocus Algorithm Using Blind Homomorphic Deconvolution for Synthetic Aperture Radar Imaging, *IET Radar, Sonar, & Navigation*, vol. 9, no. 7, pp.900-906, July 2015.
- 45) X.-G. Xia, T. Zhang, and L. Kong, MIMO OFDM Radar IRCI Free Range Reconstruction with CP, *IEEE Transactions on Aerospace and Electronic Systems*, vol. 51, no. 3, July 2015.
- 46) Y.-H. Cao, X.-G. Xia, and S.-H. Wang, IRCI Free Co-located MIMO Radar Based on Sufficient Cyclic Prefix OFDM Waveforms, *IEEE Transactions on Aerospace and Electronic Systems*, vol. 51, no. 3, July 2015.
- 47) X. Huang and X.-G. Xia, A fine resolution frequency estimator based on double sub-segment phase difference, *IEEE Signal Processing Letters*, vol. 22, no. 8, pp. 1055-1059, Aug. 2015.

Changes in research objectives, if any: None

Change in AFOSR program manager, if any: The program manager has been changed from Dr. Jon Sjogren to Dr. Tristan Nguyen and then to Dr. Arje Nachman

Extensions granted or milestones slipped, if any: None

Include any new discoveries, inventions, or patent

disclosures during this reporting period (if none, report none): None

1.

**1. Report Type**

Final Report

**Primary Contact E-mail**

Contact email if there is a problem with the report.

xxia@ee.udel.edu

**Primary Contact Phone Number**

Contact phone number if there is a problem with the report

302-831-8038

**Organization / Institution name**

University of Delaware

**Grant/Contract Title**

The full title of the funded effort.

Robust Modulo Remaindering and Applications in Radar and Sensor Signal Processing

**Grant/Contract Number**

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0055

**Principal Investigator Name**

The full name of the principal investigator on the grant or contract.

Xiang-Gen Xia

**Program Manager**

The AFOSR Program Manager currently assigned to the award

Arje Nachman

**Reporting Period Start Date**

03/15/2012

**Reporting Period End Date**

06/14/2015

**Abstract**

We also obtained a maximum likelihood estimation (MLE) based robust CRT that has a fast algorithm that only needs to search for the solution among L elements, where L is the number of remainders and the noisy remainders follow wrapped Gaussian distributions. Then, a necessary and sufficient condition on the remainder errors for the MLE CRT to be robust was obtained. We proposed a new CP based OFDM radar signal design for the IRCI free range reconstruction SAR imaging, where the zero head and tail property is proposed at the first time, in addition to the low peak-to-average power ratio (PAPR) in both the time and the frequency domains. We obtained MIMO-OFDM SAR imaging with sufficient CP. With our obtained MIMO-OFDM radar, it achieves IRCI free range reconstruction, collect the full spatial diversity from all the MIMO antennas, and maintains the same range resolution as that in a single antenna radar with the same total bandwidth. We obtained a new MIMO-OFDM radar using circularly shifted Zadoff-Chu sequences.

**Distribution Statement**

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

**Explanation for Distribution Statement**

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

DISTRIBUTION A: Distribution approved for public release.



## SF298 Form

Please attach your [SF298](#) form. A blank SF298 can be found [here](#). Please do not password protect or secure the PDF. The maximum file size for an SF298 is 50MB.

[sf298\\_Xia\\_final\\_2015.pdf](#)

**Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.**

[Final\\_2015.pdf](#)

**Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.**

### Archival Publications (published) during reporting period:

Refereed journal publications (published) during the reporting period:

- 1) H. M. Wang, Q. Yin, and X.-G. Xia, Distributed Beamforming for Physical-Layer Security of Two-Way Relay Networks, IEEE Transactions on Signal Processing, vol. 60, no. 7, pp. 3532-3545, July 2012.
- 2) W. J. Wang, H. Y. Jiang, X.-G. Xia, P. C. Mu, and Q. Yin, A Wireless Secret Key Generation Method Based on Chinese Remainder Theorem in FDD Systems, Science China -- Information Sciences, vol.55, no.7, pp.1605-1616, July 2012.
- 3) Y. Liu, X.-G. Xia, and H. L. Zhang, Distributed Space-Time Coding for Full-Duplex Asynchronous Cooperative Communications, IEEE Transactions on Wireless Communications, vol. 11, no. 7, pp. 2680-2688, July 2012.
- 4) C. Zheng, G. Li, X.-G. Xia, and X. Wang, Weighted  $\ell_{2,1}$  Minimisation for High Resolution Range Profile with Stepped Frequency Radar, IET Electronics Letters, vol. 48, no. 18, pp. 1155-1156, Aug. 2012.
- 5) Y. Lu, W. Zhang, and X.-G. Xia, On Diversity and Multiplexing Tradeoff of Two-Layer D-BLAST with Group Zero-Forcing Detection, IEEE Transactions on Communications, vol. 60, no. 8, pp. 2255-2264, Aug. 2012.
- 6) L.-C. Qian, J. Xu, X.-G. Xia, and W.-F. Sun, Fast Implementation of Generalized Radon-Fourier Transform for Maneuvering Radar Target Detection, IET Electronics Letters, vol. 48, no. 22, pp. 1427-1428, Oct. 2012.
- 7) L. Shi, W. Zhang, and X.-G. Xia, On Designs of Full Diversity Space-Time Block Codes for Two-User MIMO Interference Channels, IEEE Transactions on Wireless Communications, vol. 11, pp. 4184-4191, Nov. 2012.
- 8) J. Xu, X.-G. Xia, S.-B. Peng, J. Yu, Y.-N. Peng, and L.-C. Qian, Radar Maneuvering Target Motion Estimation Based on Generalized Radon-Fourier Transform, IEEE Transactions on Signal Processing, vol. 60, pp. 6190-6201, Dec. 2012.
- 9) J. Xu, J. Yu, Y.-N. Peng, X.-G. Xia, and T. Long, Space-Time Radon-Fourier Transform and Applications in Radar Target Detection, IET Radar, Sonar & Navigation, vol. 6, no. 9, pp.846-857, 2012.
- 10) S. X. Zhang, M. D. Xing, X.-G. Xia, L. Zhang, R. Guo, and Z. Bao, Focus improvement of high squint SAR based on azimuth dependence of quadratic range cell migration correction, IEEE Geoscience and Remote Sensing Letters, vol. 10, pp. 150-154, Jan. 2013.
- 11) G.-C. Sun, M. D. Xing, X.-G. Xia, Y. Wu, and Z. Bao, Robust Ground Moving Target Imaging Using Deramp-Keystone Processing, IEEE Transactions on Geoscience and Remote Sensing, vol. 51, no. 2, pp. 966-982, Feb. 2013.

- 12) W. Rao, G. Li, X. Wang, and X.-G. Xia, Adaptive Sparse Recovery by Parametric Weighted L1 Minimization for ISAR Imaging of Uniformly Rotating Targets, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 6, no. 2, pp. 942-952, Apr. 2013.
- 13) G.-C. Sun, M.-D. Xing, X.-G. Xia, J. Yang, Y. Wu, and Z. Bao, A unified focusing algorithm (UFA) for several modes of SAR based on FrFT," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, Part II, pp. 3139-3155, May 2013.
- 14) T. Xiong, M.-D. Xing, X.-G. Xia, and Z. Bao, New applications of Omega-K algorithm for SAR data processing using effective wavelength at high squint, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, Part II, pp. 3156-3169, May 2013.
- 15) Y. Wu, G.-C. Sun, X.-G. Xia, M. D. Xing, and Z. Bao, An improved shift-and-correlation (SAC) algorithm based on the range-Keystone transform for Doppler rate estimation, *IEEE Geoscience and Remote Sensing Letters*, vol. 10, no. 4, pp. 741-745, Jul. 2013.
- 16) G.-C. Sun, M. D. Xing, X.-G. Xia, Y. F. Wu, P. P. Huang, Y. R. Wu, and Z. Bao, Multichannel full-aperture azimuth processing for beam steering SAR, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, no. 9, pp.4761-4778, Sept. 2013.
- 17) S. Zhou, M.-D. Xing, X.-G. Xia, L. Zhang, and Z. Bao, An azimuth-dependent phase-gradient autofocus algorithm for airborne/stationary bistatic SAR imagery, *IEEE Geoscience and Remote Sensing Letters*, vol. 10, no. 6, pp.1290-1294, Nov. 2013.
- 18) H.-M. Wang, M. Luo, Q. Yin, and X.-G. Xia, Hybrid Cooperative Beamforming and Jamming for Physical-Layer Security of Two-Way Relay Networks, *IEEE Transactions on Information Forensics & Security*, vol.8, no. 12, pp.2007-2020, Dec. 2013.
- 19) S.-X. Zhang, M.-D. Xing, X.-G. Xia, Y.-Y. Liu, R. Gao, and Z. Bao, A robust channel-calibration algorithm for multi-channel in azimuth HRWS SAR imaging based on local maximum-likelihood weighted minimum entropy, *IEEE Transactions on Image Processing*, vol.22, pp.5294-5305, Dec. 2013.
- 20) Li Xiao and X.-G. Xia, A Generalized Chinese Remainder Theorem for Two Integers, *IEEE Signal Processing Letters*, vol. 21, no. 1, pp. 55-59, Jan. 2014.
- 21) Y.-F. Wu, G.-C. Sun, X.-G. Xia, M.-D. Xing, J. Yang, and Z. Bao, An azimuth frequency non-linear chirp scaling (FNCS) algorithm for TOPS SAR imaging with high squint angle, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 7, no. 1, pp.213-221, Jan. 2014.
- 22) W. Rao, G. Li, Q. Wang, and X.-G. Xia, Comparison of parametric sparse recovery methods for ISAR image formation, *Science China--Information Sciences*, vol. 57, no. 2, 022315:1-022315:12, Feb. 2014.
- 23) B. Yang, W. J. Wang, X.-G. Xia, and Q. Yin, Phase detection based range estimation with a dual-band robust Chinese remainder theorem, *Science China -- Information Sciences*, vol. 57, no. 2, 022302:1-022302:9, Feb. 2014.
- 24) T. Xu and X.-G. Xia, A Diversity Analysis for Distributed Interference Alignment Using the Max-SINR Algorithm, *IEEE Transactions on Information Theory*, vol. 60, no. 3, pp. 1857-1868, Mar. 2014.
- 25) W. Rao, G. Li, X. Wang, and X.-G. Xia, Parametric Sparse Representation Method for ISAR Imaging of Rotating Targets, *IEEE Transactions on Aerospace and Electronic Systems*, vol. 50, no. 2, pp. 910-919, April 2014.

- 26) L.-C. Qian, J. Xu, X.-G. Xia, W.-F. Sun, T. Long, and Y.-N. Peng, Wideband scaled Radon Fourier transform for high-speed radar target detection, *IET Radar, Sensor, and Navigation*, vol. 8, no. 5, pp. 501-512, 2014.
- 27) S.-X. Zhang, M.-D. Xing, X.-G. Xia, L. Zhang, R. Guo, Y. Liao, and Z. Bao, Multi-Channel HRWS SAR Imaging Based on Range-Variant Channel-Calibration and Multi-Doppler-Direction Restriction Ambiguity Suppression, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, no. 7, pp. 4306-4327, July 2014.
- 28) X. Li, M. Xing, X.-G. Xia, G.-C. Sun, Y. Liang, and Z. Bao, Deramp Space-Time Adaptive Processing for Multichannel SAR Systems, *IEEE Geoscience and Remote Sensing Letters*, vol. 11, no. 8, pp. 1148-1452, Aug. 2014.
- 29) F. Zhou, G.-C. Sun, X.-G. Xia, M.-D. Xing, and Z. Bao, Stepped frequency synthetic preprocessing algorithm for inverse synthetic aperture radar imaging in fast moving target echo model, *IET Radar, Sonar, and Navigation*, vol. 8, no. 8, pp. 864-874, 2014.
- 30) S.-X. Zhang, M.-D. Xing, X.-G. Xia, R. Guo, and Z. Bao, A Novel Moving Target Imaging Algorithm for HRWS SAR Based on Local Maximum-likelihood Minimum Entropy in Range Frequency," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, no. 9, pp. 5333-5348, Sept. 2014.
- 31) T. Zhang, X.-G. Xia, and L. Kong, IRCI Free Range Reconstruction for SAR Imaging with Arbitrary Length OFDM Pulse, *IEEE Trans. on Signal Processing*, vol. 62, no. 18, pp. 4748-4759, Sept. 2014.
- 32) L. Xiao, X.-G. Xia, and W.-J. Wang, Multi-Stage Robust Chinese Remainder Theorem, *IEEE Trans. on Signal Processing*, vol. 62, no. 18, pp. 4772-4785, Sept. 2014.
- 33) J. Yang, G.-C. Sun, M. Xing, X.-G. Xia, Y. Liang, and Z. Bao, Squinted TOPS SAR Imaging Based on Modified Range Migration Algorithm and Spectral Analysis, *IEEE Geoscience and Remote Sensing Letters*, Vol. 11, No. 10, pp. 1707-1711, Oct. 2014.
- 34) T.-X. Zhang and X.-G. Xia, OFDM Synthetic Aperture Radar Imaging with Sufficient Cyclic Prefix, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 53, No. 1, pp. 394-404, Jan. 2015.
- 35) H.-M. Wang, T.-X. Zheng, and X.-G. Xia, Secure MISO Wiretap Channels With Multi-Antenna Passive Eavesdropper: Artificial Noise vs. Artificial Fast Fading, *IEEE Transactions on Wireless Communications*, vol. 14, no. 1, pp. 94-106, Jan. 2015.
- 36) S.-X. Zhang, M.-D. Xing, X.-G. Xia, R. Guo, and Z. Bao, Robust Clutter Suppression and Moving-Target Imaging approach for Multi-channel in Azimuth High-Resolution and Wide-Swath Synthetic Aperture Radar, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 2, pp. 687-709, Feb. 2015.
- 37) W. Wang, X.-P. Li, X.-G. Xia, and W.-J. Wang, The largest dynamic range of a generalized Chinese remainder theorem for two integers, *IEEE Signal Processing Letters*, vol. 22, no. 2, pp. 254-258, Feb. 2015.
- 38) C. Wang, H.-M. Wang, and X.-G. Xia, Hybrid Opportunistic Relaying and Jamming with Power Allocation for Secure Cooperative Networks, *IEEE Transactions on Wireless Communications*, vol. 14, no. 2, pp. 589-605, Feb. 2015.
- 39) L. Xiao and X.-G. Xia, Error Correction in Polynomial Remainder Codes with Non-Pairwise Coprime Moduli and Robust Chinese Remainder Theorem for Polynomials, *IEEE Transactions on Communications*, vol. 63, no. 3, pp.605-616, March 2015.

- 40) G. Xu, M.-D. Xing, X.-G. Xia, L. Zhang, Y.-Y. Liu, and Z. Bao, Sparse Regularization of Interferometric Phase and Amplitude for InSAR Image Formation Based on Bayesian Representation, IEEE Transactions on Geoscience and Remote Sensing, vol. 53, no. 4, pp. 2123-2136, April 2015.
- 41) C. Meng, J. Xu, X.-G. Xia, F. Liu, T. Long, E. Mao, J. Yang, and Y. Peng, MIMO-SAR waveforms separation based on virtual polarization filter, Science China -- Information Sciences, vol. 58, no. 4, pp.042301:1--042301:12, April 2015.
- 42) Y.-H. Cao and X.-G. Xia, IRCI free MIMO-OFDM SAR using circularly shifted Zadoff-Chu sequences, IEEE Geoscience and Remote Sensing Letters, vol. 12, no. 5, pp.1126-1130, May 2015.
- 43) W.-J. Wang, X.-P. Li, W. Wang, and X.-G. Xia, Maximum Likelihood Estimation Based Robust Chinese Remainder Theorem for Real Numbers and Its Fast Algorithm, IEEE Transactions on Signal Processing, vol. 63, no. 13, pp.3317-3330, July 2015.
- 44) P. Shao, M.-D. Xing, X.-G. Xia, Y.-C. Li, X. Li, and Z. Bao, Autofocus Algorithm Using Blind Homomorphic Deconvolution for Synthetic Aperture Radar Imaging, IET Radar, Sonar, & Navigation, vol. 9, no. 7, pp.900-906, July 2015.
- 45) X.-G. Xia, T. Zhang, and L. Kong, MIMO OFDM Radar IRCI Free Range Reconstruction with CP, IEEE Transactions on Aerospace and Electronic Systems, vol. 51, no. 3, July 2015.
- 46) Y.-H. Cao, X.-G. Xia, and S.-H. Wang, IRCI Free Co-located MIMO Radar Based on Sufficient Cyclic Prefix OFDM Waveforms, IEEE Transactions on Aerospace and Electronic Systems, vol. 51, no. 3, July 2015.
- 47) X. Huang and X.-G. Xia, A fine resolution frequency estimator based on double sub-segment phase difference, IEEE Signal Processing Letters, vol. 22, no. 8, pp. 1055-1059, Aug. 2015.

**Changes in research objectives (if any):**

**Change in AFOSR Program Manager, if any:**

The program manager has been changed from Dr. Jon Sjogren to Dr. Tristan Nguyen and then to Dr. Arje Nachman

**Extensions granted or milestones slipped, if any:**

**AFOSR LRIR Number**

**LRIR Title**

**Reporting Period**

**Laboratory Task Manager**

**Program Officer**

**Research Objectives**

**Technical Summary**

**Funding Summary by Cost Category (by FY, \$K)**

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

**Report Document**

**Report Document - Text Analysis**

**Report Document - Text Analysis**

**Appendix Documents**

**2. Thank You**

**E-mail user**

Aug 27, 2015 09:56:04 Success: Email Sent to: xxia@ee.udel.edu