Robust Modulo Remaindering and Applications in Radar and Sensor Signal Processing

Xiang-Gen Xia
UNIVERSITY OF DELAWARE

08/27/2015
Final Report

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REPORT DOCUMENTATION PAGE

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<td>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.</td>
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<td>Robust Chinese remainder theorem, generalized Chinese remainder theorem, undersampling, SAR imaging, phase unwrapping, OFDM SAR, MIMO-OFDM SAR</td>
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DISTRIBUTION A: Distribution approved for public release.
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:


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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

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Include any new discoveries, inventions, or patent disclosures during this reporting period (if none, report none): None

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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.

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12) W. Rao, G. Li, X. Wang, and X.-G. Xia, Adaptive Sparse Recovery by Parametric Weighted L1
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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,

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,

15) Y. Wu, G.-C. Sun, X.-G. Xia, M. D. Xing, and Z. Bao, An improved shift-and-correlation (SAC) algorithm
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for multi-channel in azimuth HRWS SAR imaging based on local maximum-likelihood weighted minimum


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scaling (FNCS) algorithm for TOPS SAR imaging with high squint angle, IEEE Journal of Selected Topics in

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24) T. Xu and X.-G. Xia, A Diversity Analysis for Distributed Interference Alignment Using the Max-SINR

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.

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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)

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