UNIVERSITY OF TECHNOLOGY SYDNEY
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Generalized Continuous Wave Synthetic Aperture Radar

by

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Certificate of Authorship/Originality

I, Yijiang Nan, declare that this thesis, is submitted in fulfilment of the requirements for the award of PhD, in the School of Electrical and Data Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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ABSTRACT

Synthetic aperture radar (SAR) suffers from several intrinsic limitations caused by the slow time sampling in azimuth. In this thesis, a generalized continuous wave synthetic aperture radar (GCW-SAR) is developed based on one-dimensional (1-D) continuous wave (CW) signalling, thus removing these limitations.

GCW-SAR reconstructs a radar image originally by correlating the received one-dimensional raw data after self-interference cancellation (SIC) with predetermined location dependent reference signals. The SIC in GCW-SAR is discussed and then the system geometry and the original imaging method are proposed. To reduce the complexity, a novel piecewise constant Doppler (PCD) algorithm based on the linear approximation of the slant range, is proposed reconstructing a SAR image recursively in azimuth. Additionally, a faster and more flexible PCD implementation, called decimated PCD algorithm, is proposed, by which the image azimuth spacing can be extended further reducing the computational cost significantly.

The PCD algorithm is the key technique for the GCW-SAR. This thesis presents a theoretical PCD imaging performance analysis. Firstly, the difference between conventional SAR imaging and PCD imaging is revealed. Exact ambiguity function expressions of the PCD imaging in range and azimuth are then derived respectively. An error function of the PCD imaging is further defined and shown to be a function of an image quality factor to quantify the imaging performance. The decimated PCD imaging error is also analyzed accordingly.

Passive GCW-SAR system and millimeter wave GCW-SAR system with deramp-on-receive are proposed respectively. A modified PCD algorithm suited for passive GCW-SAR is proposed to remove the conventional passive SAR limitations. Using deramping technique can drastically reduce the receiving sampling rate and the millimeter wave carrier enables high azimuth resolution as well as short synthetic aperture which in turn significantly reduces the imaging computational complexity. The effects of deramp-on-receive in PCD imaging is analyzed accordingly.

Finally, a real GCW-SAR experimental system is developed and the experimental results are presented. This practical system consists of four subsystems, i.e., receiver frontend subsystem, radar control subsystem, positioning control subsystem and digital imaging subsystem. The first two parts are constructed by using the AWR1843 single-chip 77-GHz FMCW radar sensor made by Texas Instruments, the third by using the linear moving platform made by FUYU Technology company, and the digital imaging is possessed by MATLAB off-line processing in a personal computer (PC). The experimental results validate the advantages of the proposed GCW-SAR system.

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List of Publications

Journal Papers

J-1. **Y. Nan**, X. Huang and Y. J. Guo, "Generalized Continuous Wave Synthetic Aperture Radar for High Resolution and Wide Swath Remote Sensing," *in IEEE Transactions on Geoscience and Remote Sensing*, vol. 56, no. 12, pp. 7217-7229, Dec. 2018.

J-2. **Y. Nan**, X. Huang and Y. J. Guo, "A Millimeter Wave GCW-SAR Based on Deramp-on-Receive and Piecewise Constant Doppler Imaging," *in IEEE Transactions on Geoscience and Remote Sensing*, vol. 58, no. 1, pp. 680-690, Jan. 2020 .

J-3. **Y. Nan**, X. Huang and Y. J. Guo, "Piecewise Constant Doppler Algorithm: Performance Analysis and Further Simplification," *to appear in IEEE Transactions on Aerospace and Electronic System*, (Accepted on 12-Feb-2020).

Conference Papers

C-1. **Y. Nan**, X. Huang and Y. J. Guo, "A Generalized Continuous Wave Synthetic Aperture Radar," *2017 IEEE 85th Vehicular Technology Conference (VTC Spring)*, Sydney, Australia, Jun., 2017.

C-2. **Y. Nan**, X. Huang and Y. J. Guo, "Passive synthetic aperture radar imaging with piecewise constant Doppler algorithm," *2017 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, Verona, Italy, Sep., 2017.

C-3. A. T. Le, **Y. Nan**, L. C. Tran, X. Huang, Y. J. Guo and Y. Vardaxoglou, "Analog Least Mean Square Loop for Self-Interference Cancellation in Generalized Continuous Wave SAR," *2018 IEEE 88th Vehicular Technology Conference (VTC2019-Fall)*, Chicago, IL, USA, Aug., 2018.

C-4. **Y. Nan**, X. Huang and Y. J. Guo, "A Fast Piecewise Constant Doppler Algorithm for generalized Continuous Wave Synthetic Aperture Radar," *2019 International Conference on Radar (RADAR2019)*, Toulon, France, Sep., 2019.

Patents

P-1. X. Huang, Y. Nan, and Y. J. Guo, "Imaging Synthetic Aperture Radar System and Method", AU2017902109.

Contents

List of Figures

Abbreviation

ADC: Analog-to-Digital Converter

AoA: Angle-of-Arrival

BPA: Back-Projection Algorithm

CSA: Chirp Scaling Algorithm

CW: Continuous Wave

DPCA: Displaced Phase Center Antenna

DVB-T: Digital Video Broadcasting-Terrestrial

FD: Full-Duplex

FFT: Fast Fourier Transformation

FM: Frequency Modulated

FMCW: Frequency Modulated Continuous Wave

GCW-SAR: Generalized Continuous Wave Synthetic Aperture Radar

GUI: Graphical User Interface

HRWS: High Resolution and Wide Swath

IF: Intermediate Frequencies

LFM: Linearly Frequency Modulated

LNA: Low Noise Amplifier

LPF: Low-Pass Filters

MIMO: Multiple Input Multiple Output

One-Dimensional: 1-D

PA: Power Amplifier

PC: Personal Computer

PCD: Piecewise Constant Doppler

PRF: Pulse Repetition Frequency

PRI: Pulse Repetition Interval

RCM: Range Cell Migration

RCMC: Range Cell Migration Compensation

RCS: Radar Cross Section

RDA: Range Doppler Algorithm

RVP: Residual Video Phase

SAR: Synthetic Aperture Radar

SIC: Self-Interference Cancellation

SIR: Signal-to-Interference Ratio

SNR: Signal-to-Noise Ratio

SoP: Sense-on-Power

SPI: Serial Peripheral Interface

SRC: Secondary Range Compression

SS-BSAR: Space-Surface Bistatic Synthetic Aperture Radar

Two-Dimensional: 2-D

UAV: Unmanned Aerial Vehicle

WDA: Wavenumber Domain Algorithm