Three-Dimensional Inverse Synthetic Aperture Radar

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Abstract:
Inverse Synthetic Aperture Radar (ISAR) is a well-known technique to obtain high-resolution radar images of non-cooperative targets. ISAR images have been largely used to classify and recognise targets and ISAR technology is nowadays employed and integrated in modern radar systems. Nevertheless, despite decades of research and development work in ISAR imaging, two-dimensional (2D) ISAR images present some intrinsic drawbacks that limit the effectiveness of their use for target classification and recognition. Some of these limitations come from the unpredictability and uncontrollability of the image projection, which transforms three-dimensional (3D) targets in 2D images. One very effective way of overcoming this problem is to form 3D ISAR images instead of 2D ones.

This tutorial will present a unique walkthrough 3D ISAR imaging, including concepts, algorithms, systems and real data examples, which will provide the attendants the necessary tools for a full understanding of this new technology.

Intended Audience:

Attendees should have an introductory understanding of radar systems, radar phenomenology, and radar signal processing. The tutorial will be completed with a brief but effective introduction to ISAR imaging, which will make it a stand-alone tutorial also for those who do not have a full understanding of traditional ISAR imaging.

Learning Outcomes:
In this tutorial, elements ISAR will be introduced in terms of system geometry, signal modelling, image reconstruction and interpretation. 3D ISAR imaging will then be introduced in order to provide the theoretical and conceptual basis for a solid understanding of this technology. The attendants will also have the opportunity to see real 3D ISAR systems and real data for a full comprehension of what is required to obtain 3D ISAR images.

Detailed Description:
This tutorial will be start with a brief introduction to ISAR imaging, including details about the shortcomings of 2D ISAR imaging. The introductory section will be followed by a quick review of known methods for forming 3D ISAR images as known in the literature. Pros and cons of such methods will be highlighted. 3D Interferometric ISAR imaging will be then introduced starting from the system characteristics, and then from a signal processing point of view. A robust algorithm for forming 3D interferometric ISAR images will be then detailed that will represent the backbone for a number of implementations of 3D ISAR imaging for a number of platforms and types of targets. Real systems and data will be displayed throughout the tutorial to provide evidence of implementation of 3D ISAR imaging.

Here below is a breakdown of the content:

1. Introduction to ISAR
    - 1.1. Concept and examples
    - 1.2. Geometry and Signal modelling
    - 1.3. ISAR image formation
    - 1.4. ISAR image interpretation and shortcomings of 2D ISAR imaging

2. 3D ISAR imaging
    - 2.1. Review of 3D ISAR imaging
    - 2.2. 3D InISAR imaging
        - 2.2.1. System perspective
        - 2.2.2. Signal modelling
        - 2.2.3. 3D InISAR image formation
    - 2.3. Examples of 3D InISAR images and their interpretation

3. Bistatic and multi-static InISAR imaging
    3.1. Bistatic and multi-static InISAR imaging
    3.3. Multi-dimensional InISAR imaging
        3.3.1. Multi-temporal InISAR imaging
        3.3.2. Multi-view InISAR imaging
        3.3.3. Full pol 3D InISAR

4. Advanced techniques for accurate InISAR imaging
    4.1. Introduction and motivation
    4.2. Image and phase co-registration

5. Implementations of InISAR
    5.2. Ship-borne InISAR
    5.3. Drone-based InISAR

Prior Presentations:

This is tutorial will be presented for the first time at the IEEE 2024 Radar Conference.

Biosketches:

Elisa Giusti obtained the specialist degree in Telecommunication Engineering from the University of Pisa in 2006 (cum Laude) and obtained the title of PhD in Remote Sensing at the Department of Information Engineering of the University of Pisa in 2010. She was a Research Fellow at the Department of Information Engineering of the University of Pisa until 2014 and subsequently she worked as a researcher at the National Interuniversity Consortium for Telecommunications (CNIT), and in particular at the National Radar Laboratory and Surveillance Systems (RaSS), where she still works today and where she holds the role of senior researcher (Head of Research). She participated in numerous international research projects, funded by Italian ministries (Ministry of Defence, Ministry of Economic Development, Ministry of University and Research) and European organizations (EDA, ESA, EC), as researcher and as technical and scientific manager. Many of the projects carried out have seen the validation of technological demonstrators through field trials. She is member of the IEEE and Associate Editor of the IEEE TCI journal. She is author of 107 papers published in international journals and conference proceedings, 1 book and 7 book chapters. She received international awards including the Fall 2021 NATO Sensors and Electronics Technology (SET) Panel Early Career Award (SPECA) and the 2016 Outstanding Information Research Foundation Book publication award for the book Radar Imaging for Maritime Observation. In 2015, she co-founded ECHOES, a radar systems-related spin-off company. Her research interests are mainly in the field of radar systems and radar data processing algorithms. She is senior member of the IEEE.

Selected publications

1. V. C. Chen, M. Martorella, “Inverse Synthetic Aperture Radar Imaging: Principles, Algorithms and Applications”, IET/Scitech Publishing, 2014
2. F. Berizzi, M. Martorella, E. Giusti, “Radar Imaging for Maritime Observation”, CRC Press, Taylor and Francis, 2016
3. M. Martorella, “Multidimensional Radar Imaging”, IET Publishing, 2019
4. F. Berizzi, E. Dalle Mese, M. Diani, M. Martorella, “High resolution ISAR imaging of maneuvering targets by means of the Range Instantaneous Doppler technique: modeling and performance analysis”, Image Processing, IEEE Transactions on , Volume: 10, No. 12, Dec. 2001, pp 1880 –1890.
5. L. Z. Zhao, M. Martorella, X. J. Fu, M. G. Gao, “Three-dimensional bistatic interferometric ISAR imaging”, Journal of Beijing Institute of Technology, Vol. 24, No. 1, March 2015, Pages: 105-109
6. D. Stagliano, E. Giusti, S. Lischi, M. Martorella, “Bistatic 3D Interferometric ISAR”, IET Radar, Sonar and Navigation, Vol. 10, No. 1, 2016, Pages: 63-75
7. F. Salvetti, M. Martorella, E. Giusti, D. Stagliano’, “Multi-view 3D InISAR Imaging”, IEEE Transactions on Aerospace and Electronic Systems, Vol. 55, No. 2, 2019, Pages: 718-733
8. E. Giusti, M. Martorella, “Passive 3D Interferometric ISAR using target-borne illuminator of opportunity”, Proceedings of the IET RSN, Vol. 13, No. 2, 2019, Pages: 190-197
9. A. Kumar, E. Giusti, F. Mancuso, S. Ghio, A. Lupidi and M. Martorella, "Three-Dimensional Polarimetric InISAR Imaging of Non-Cooperative Targets," in IEEE Transactions on Computational Imaging, vol. 9, pp. 210-223, 2023, doi: 10.1109/TCI.2023.3248942.
10. J. Park, R. G. Raj, M. Martorella and E. Giusti, "Multilook Polarimetric 3-D Interferometric ISAR Imaging," in IEEE Transactions on Aerospace and Electronic Systems, vol. 58, no. 6, pp. 5937-5943, Dec. 2022, doi: 10.1109/TAES.2022.3174831.
11. E. Giusti, S. Ghio and M. Martorella, "Drone-based 3D interferometric ISAR Imaging," 2021 IEEE Radar Conference (RadarConf21), Atlanta, GA, USA, 2021, pp. 1-6, doi: 10.1109/RadarConf2147009.2021.9455271.
12. E. Giusti, S. Ghio and M. Martorella, "Drone-based 3DInISAR: Experimental Results," 2023 IEEE Radar Conference (RadarConf23), San Antonio, TX, USA, 2023, pp. 1-6, doi: 10.1109/RadarConf2351548.2023.10149656.