Ph.D. proposal: study of the long dwelling SAR mode

This is a joint PhD thesis between Université Paris Saclay (CentraleSupélec) and University of Ancona, in Italy. The PhD candidate will spend half of the time in each university.

Context

In recent years, a new satellite radar imaging mode has emerged: the Long Dwelling SAR mode, enabling very high spatial resolutions, down to a few tens of centimetres and potentially around 16 cm for future missions. Several commercial operators already provide such imagery, including ICEYE, Umbra, and Capella Space.

Improving SAR spatial resolution has a strong impact on security and surveillance applications, such as monitoring critical infrastructures (ports, airports, bridges, dams), as well as on the detailed characterization of vehicles, ships, aircraft, and more generally of mobile or man-made targets.

SAR image resolution is defined along two dimensions:

- range resolution, mainly determined by the sensor bandwidth;
- azimuth resolution, governed by the illumination time and the physical antenna aperture.

The Long Dwelling Mode specifically aims at increasing the illumination time of a given target, by steering the antenna during acquisition, thereby significantly improving azimuth resolution.

Scientific Issues

This acquisition strategy has an important consequence: during image acquisition, a ground target is illuminated over a wide azimuth angular span (typically up to ±20°).

For isotropic targets, this angular variation has little impact. However, for most realistic targets and scenes, it introduces significant effects:

- variations of the target radiation pattern in both amplitude and phase as a function of azimuth angle;
- variations of the transmit and receive polarization vectors, which can no longer be considered invariant over the full illumination time;
- potential impacts on radiometric, phase, and polarimetric calibration, as well as on image interpretation.

Research Objective

The objectif of this Ph.D. thesis is to investigate the signature of a target illuminated in Long-Dwelling mode using electromagnetic (EM) modelling. To achieve this, the Ph.D. candidate will use a tool developed during a previous Ph.D thesis, and which enables fast simulations of the EM response of a target for multiple azimuth angles.

Organisation of the PhD work

During the first year, the PhD candidate will work in parallel, on the analysis of SAR images acquired in Long Dwelling Mode and on the simulation of SAR images in this mode at X-band (around 10 GHz). The main objective is to characterize these images.

At first, the acquisition geometry must be rigourously defined. What are the incidence angles and how do they vary along the azimuth and the range directions depending on the acquisition mode? How are the transmit and receive polarization vectors defined for the different acquisition modes? Then the characteristics of the SAR images will be studied. How are the amplitude/intensity and Co-Pol & Cross-Pol Phases Differences (CPD and XPD) when available distributed in Long-Dwelling mode compared with regular mode, both over the full images and for some Regions of Interest (ROIs)? How these distributions in regular mode compare with those of classical SAR images under similar configurations, if available? Can some specific targets, such as permanent scatterers, provide useful insight into the properties of these new images. It will also be important to evaluate the impact on this new acquisition mode on the applicability classical SAR image processing methods.

On the modeling side, we will focus on canonical targets, such as a metallic sphere, plate, or more advanced like metallic dihedral or trihedral corner reflectors. The first step will be to verify that polarimetric SAR images can be rigorously simulated in the regular acquisition mode. This validation will rely on the analysis of the intensities, the CPD/XPD, and some representations such as the Pauli basis decomposition. For this purpose, we will jointly use an in-house tool we have previously developed and a commercial EM software, FEKO. The latter will serve to simulate the EM response for some specific incidence and receiving angles, while the former will use these responses to emulate the full scattering pattern, required to form afterwards the SAR image.

At the end of the first year, the PhD student will have identified the main advantages and limitations of this Long Dwelling SAR acquisition mode and clarified the main issues associated with the simulations and the use of such images.

During the second year, the PhD candidate will focus on the EM aspects.
One anticipated difficulty arises from the fact that the polarization vectors vary throughout the azimuth illumination interval. This issue must first be carefully formalized and compared with similar effects encountered in some super resolution modes, with TerraSAR-X for instance. In particular, the following questions will be addressed: How sensitive is SAR image formation to azimuth-angle shifts in the polarization definition? Is this sensitivity identical for both polarizations?

If the SAR image formation proves to be highly dependent on this aspect, an alternative polarization reference frame will need to be defined. One possible solution would be to introduce a reference frame in which the polarization vectors remain constant throughout the acquisition.

The third year will be dedicated to investigating the possible exploitation of these non conventional SAR images. A key question will be whether such images can be properly calibrated, and if so, how? One possible approach may consist in restricting the processing to only part of the acquisition interval, in order to satisfy the angular constraints required to form a conventional SAR image. If this proves necessary, new processing tools can be imagined to exploit the full acquisition of the

Long Dwelling SAR mode or existing tools may be adapted. This final phase of the PhD will strongly depend on the results obtained the first two years.

Expected skills

Candidates should ideally have a background in radar remote sensing, and basic knowledge in electromagnetics, signal processing, or applied physics. Experience with electromagnetic simulation tools. The candidate should demonstrate strong analytical abilities, scientific curiosity, and the capacity to work autonomously in an interdisciplinary research environment.

The lab

SONDRA is a joint lab between France and Singapore, located at CentraleSupélec, Paris and is dedicated to radar remote sensing. The team's Physics and modelling aims to use the physical understanding of the interactions between radar waves and their surrounding environment to improve classical detection tools or propose new approaches better suited to our specific needs. We have worked for twenty years on the radar signature of different forests (tropical, boreal, and temperate), using various radar techniques such as radiometry, polarimetry and interferometry, in bistatic configurations, and recently unsupervised machine learning algorithms.

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