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Spatial Synthetic Aperture Radar Imaging for Archeology - Multisensor Approaches and Machine Learning

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Description of the subject:

Archaeological research regularly uses remote sensing tools that allow the ground surface or subsoil to be explored non-intrusively for prospection or diagnosis before deciding on an excavation campaign.

The analysis of remote sensing images can be carried out at 3 main levels:

- On the ground, by analyzing geophysical parameters (electrical and magnetic properties and / or contrasts) of the area of interest or by using a Ground Penetrating Radar (GPR). These analyses are usually carried out by archaeologists, either by using portable devices or from a vehicle towing the measurement system. The surface area covered by these instruments is thus relatively limited.
- Airborne: optical and / or infrared aerial imagery has been used intensively for archaeological research. However, one can also think to use lidar (in order to obtain the microtopography of the ground under a plant cover or under water in the case of bathymetry) or synthetic aperture radar (SAR) images. Optical, infrared or SAR images are usually acquired within the framework of specific campaigns using a plane, a helicopter or a drone. Drones take a growing place due to an easy implementation on the technical level. However, these airborne assets are generally subjected to a request for authorization to fly over. The analyzed areas are often larger than the previous ones, but remain limited.
- Satellites: they produce optical, infrared or radar data allowing the topography of the ground to be obtained. However, satellite data have generally a lower resolution and an higher noise level than airborne ones, cover large areas with a revisit rate of a few days and do not require an authorization to fly over. As a consequence, satellites make it possible to conduct archaeological, preventive or programmed research, not only at the local scale but also over very large areas.

The combination of several of the remote sensing data is generally important to ensure the quality of a survey or diagnosis.

This thesis focuses on space-based synthetic aperture radars, which have already proved to be successful for many applications. Its main objective is to propose innovative methods for the detection of archaeological sites using radar images possibly fused with other image sources. Regarding the results already obtained for archaeology by means of radar images, we can mention:

- Data collected by the SIR-C/X-SAR imager radar onboard Space Shuttle Endeavour in 1994, which led to the discovery of a major archaeological monument at the Angkor site (Cambodia), which was unknown and totally hidden under the rainforest, or the discovery of the lost city of Ubar in the Arabian Peninsula.
- The BIOMASS mission of the European Space Agency (ESA) which will be launched in 2021 will embark a low frequency polarimetric imaging radar (P band) which will offer new opportunities for remote sensing of archaeological sites (due to the penetration capacities through the environments observed at the considered wavelengths). In preparation for this space mission, ONERA carried out an airborne SAR measurement in P-band (435 MHz) in 2010 in the Sahara desert in the south of Tunisia. This data was used to highlight a buried pipeline towards the oasis of Ksar Ghilane (32.98°N-9.63°E). However, this kind of data has been explored with a limited interest. Thus, methodological works need to be conducted to identify the most efficient radar parameters for archaeological applications.
- Without having knowledge of archaeological applications conducted with the Japanese radar satellite ALOS-2 PALSAR-2 in L-band (1,257 GHz), we expect interesting capacities, because it can penetrate in the vegetation or the ground, certainly less than BIOMASS , but with a much better resolution (10 m in fine stripmap mode).
- Data acquired by Sentinel-1 (COPERNICUS program from ESA) with a resolution of 20 m (pixels of 10 m) made it possible to highlight a portion of the route of the *Via Domitia* in Occitanie (west of Leucate, France), which was unexpected.
- TerraSAR-X operates at 9.65 GHz and has several imaging mode. The most resolved mode is characterized by a spatial resolution up to 50 cm. TerraSAR-X was used with TanDEM-X (topography) on Syria to assess the impacts of the civil war. The CosmoSkyMed satellite of the Italian space agency (ASI) has similar capabilities.

Thesis organization:

After a state of the art about remote sensing for archaeological research, the candidate will:

- Study the capabilities of space radars regarding various archaeological needs for which they are potentially interesting;
- Determine and implement the most appropriate processing for the various scenarios related to archaeological needs;
- Establish a catalogue of radar signatures for various types of archaeological remains.
- Analyze the potential interest of fusing radar data with other image sources (optical, infrared, topographical) in order to increase the quality of detection of archaeological sites by Machine Learning methods.

Several ranges of radar images can be studied in this thesis depending on the following characteristics :

- Frequency bands: P (Biomass), L (ALOS), C (Sentinel-1), X (Terrasar-X, COSMO-Skymed);
- Resolution: Biomass, Sentinel-1, ALOS-2-PALSAR-2 / Terrasar-X / COSMO-Skymed (depending on the mode: spotlight, stripmap, scanSAR);
- Various polarimetric modes.

Different problems will be investigated in this thesis:

- Analyze the measurement for several typical cases of vestiges in terms of:
    - Geometry: old road characterized by a linear strip with the presence of exogenous pebbles, large parallelepiped cut stones, vestiges of a building made up of numerous stones. We will begin by studying the response of canonical targets in the different polarimetric channels;
    - Roughness: set of stones of different sizes distributed over the ground, irregularities in the ground due to the presence of underlying vestiges;
    - Burial: ability of the radar signal to reveal vestiges buried in the ground or under the vegetation cover, depending on its characteristics and the nature of the soil or vegetation.

- Study appropriate processings highlighting archaeological remains.

- In combination with other image types (multispectral optical and infrared, or topographical):
    - Investigate fusion methods for the available images to better target areas of interest;
    - Propose methods (accounting for the diversity of identifiable archaeological remains and their signatures);
    - Study machine learning methods in order to identify archaeological sites and to carry out automatic mapping (localization appropriate classification of sites and extent of these sites)

- Control measurement artifacts,

- Take into account acquisition conditions for the different images:
    - Direction of arrival for the radar signal, ...
    - Meteorology: humidity, rain before or during the shooting, …

At the end of this doctoral research work, a set of methodological tools will be proposed to archaeologist, depending on the type of vestige to be detected. These tools have to be adapted to remote sensing data acquired from space and will be validated experimentally.

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Candidate Profile Student of engineer or master degree with specialization in radar or in image processing.

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