PhD title:

“Through-the-Wall Imaging, processing techniques and experimentation”

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Keywords: Numerical simulation of electromagnetic signals, antenna systems, scattering problems, hybridization of simulations and experiments, Radar, Synthetic Aperture Radar, Migration, signal processing, multistatic analysis, physics of electromagnetic waves, Doppler effect

Context

The techniques associated with through wall imaging have been of increasing interest since latest microwave technologies have become affordable. Detection through the walls makes it possible, beyond the structure of the building to identify the nature of activities in closed areas, to detect and track fixed or mobile objects/humans [Moe13] [Thi11]. The usability of such technique covers civil (rescue operation) and military domains (assistance in neutralizing threats to property and persons).

To that purpose, electromagnetic waves are very effective because of their ability to penetrate building materials and to give access to information concerning targets placed behind opaque structures. The technique of imaging through the walls is a multidisciplinary domain. It is linked to Radar, signal and image processing, microwave electronics, electromagnetic theory (EM) in the Maxwell domain, forward and inverse problems analysis, antenna optimization. These are coupled with experimental assessment in laboratory controlled environment and performance qualification in real-life conditions.

Through Wall Imaging (TWI) is based on a thorough understanding of the interactions of electromagnetic waves with a given environment. In this PhD project, we propose to highlight the contribution of a better modeling of the forward problem and its consequences on the quality of the reconstructed images. It is necessary to take into account all the parameters that are relevant, namely the sensors (transmitting and receiving antennas), the propagation medium interfaces (air + walls), imaging algorithms, signal polarization/bandwidth, reconstruction resolution. The aim of this PhD is to design of a through-wall imaging system viewed as a whole: from hardware to imaging algorithms.

Description of PhD program

These last years, one has been addressing many issues fitting to the above description during doctoral investigations in the different laboratories involved in this PhD project. Indeed, there are points of convergence in the analysis of TWI problem and other non-invasive technique ; ground penetrating radar (GPR). Both Institut Fresnel and GeePs laboratories have developed long-standing know-how around this [Sor20] [Eyr18] [Liu18] [Abo21]. In addition, Sondra laboratory has an effective expertise in antenna design/optimization and radar processing technique [Hin17][Hin14]. The supervising team can also be supported by data-scientist if needed for the investigation purpose.

The thesis aims at studying the adaptability of GPR techniques in the context of TWI. The "bidirectional" interactions between software with the dedicated hardware are crucial. We aim at constructing/validating a proof of concept prototype based on real-time imaging technique in order to localize a static or a moving target behind an opaque obstacle. The RF-electronics and the dedicated hardware may be off-the-shelf components, but this may reduce the degrees of freedom of imaging protocols/procedures: time or frequency data, modulation technique, data acquisition, calibration....

A large inventory of literature devoted to TWI is needed. Learning about state of art, the PhD student strategy is to reach a comprehensive coverage of different aspects from electromagnetic modeling to an experimental setting (hardware configuration).

The electromagnetic properties of the walls from the material point of view are taken into account to study and model their effects over the transmitted signals [Tha17][Cou18]. These are to be integrated during measurement data correction/processing for the detection/localization of the targets. On this particular point, the use of low profile ultra wide band antenna and their networking is to be expected [Yek16] [Ser13].

Network development and system control mechanisms are one of the important experimental bricks to be implemented for the validation of the imaging technique across walls. A significant part of the analysis of TWI will be devoted to the study of the algorithms used for the resolution of the inverse problem depending on mono- bi- or multi-static configurations [Cat09] [Gen13] [Sol07]. The appropriateness of the approach and the physical model adopted will be justified.

Moreover, for the validation purposes, one need to investigate synthetic data resulting from forward problems electromagnetic modeling taking into account the EM propagation through the walls as well as the dispersion effects and their effect on the image quality of reconstructed targets.

Synthetic Aperture radar as well as migration techniques are privileged since it allows a real time target localization. However, one have to study the performances and the adaptability of these techniques in the context of TWI [Deh08] [Wen15].

As such, the student will propose guidelines, on the design of TWI systems that takes into account the hardware and microwave imaging formalism as well as the propagation medium, the signal dispersion, the signal bandwidth, polarization, antenna radiation pattern and networking. This PhD subject opens wide perspectives and one will first concentrate on non-moving targets. Yet, it is possible to propose fast acquisition schemes based on a reduced data volume.

Proposition of progress

1st year: Bibliography on propagation mechanisms and impact on the transmitted signal to correct and/or process images of the reconstructed/detected/localized targets. The effects of attenuation and dispersion of the walls must be identified as a function of the angles of incidence and the polarization of the transmitting/receiving antennas. First ideas on the design of the antenna elements and their networking (network development and system control mechanisms).

2nd year: Continuation on the hardware design towards proof of concept prototype. Start studying on beam forming techniques and the analysis of the effects of different wall types on the quality of the focusing. Different patterns and algorithms that can be used for imaging are to be proposed and evaluated. The student will also start the study of the algorithms used for the resolution of the inverse problem exploiting a multi-static matrix of the scattered field. At this stage validation will be with synthetic data.

3rd year: Proof of concept prototype and validation of algorithms on real data and synthetic data (where needed). Potentially considering compressive sensing techniques for fast acquisition techniques.

Thesis supervision

The work is to be run within a tight cooperation between the GeePs laboratory, the Institut Fresnel and the Sondra laboratory. The proposed PhD topic offers, as aforementioned strong means to develop the student's expertise in challenging wave modeling/ numerical methods, inversion/imaging, and experimentation. Carrying out/disseminating cutting-edge research in academic, multi-disciplinary framework is an obvious

asset. This will offer to him/her a lot of opportunities in academia and industry, as being engaged in many fields in a strong joint way, tuned to his/her own expertise and wishes as needed.

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PhD Diploma: to be delivered by CentraleSupélec – Université Paris Saclay, France.

Profile and skills

The candidate, with a Master's degree (in physics, electrical–telecommunication–microwave engineering, signal processing), should have good skills in electromagnetism. Skills in antenna design and experimentation, electromagnetic modeling and numerical simulation would be a real asset. He/she should be willing to perform numerical developments, for computer programming and development purposes (Matlab, Python) to illustrate his/her work at the best level and be involved in experimental teamwork. Depending on the curriculum of the PhD student, the course of his first year can evolve.

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