Research activities

This section presents my research activities carried out during my research master's, my international master's as well as my doctoral thesis. As shown in figure 1, my activities mainly concern statistical signal and image processing, which deals with the resolution of inverse problems such as source separation (i.e., spectral unmixing, non-negative matrix factorization), segmentation, classification, constrained parametric and non-parametric estimation, clustering, as well as statistical modeling of the images to be processed.

These inverse problems are generally ill-posed, and their solution requires the introduction of a-priori information. In my work, I solve these problems by adopting mainly two approaches: the Bayesian approach or the deterministic approach (regularization or machine learning). In the first case, the variables of interest are assumed to be random, and information is introduced via a-priori distributions. In the second case, the variables are assumed to be deterministic, and the problem is solved after introducing regularization terms. In both cases, the added information must be carefully chosen to match the statistical characteristics of the data (related to the statistical nature of the noise), as well as the known properties or constraints of the parameters of interest (sparsity, spatial correlation, total variation, non-negativity, etc).

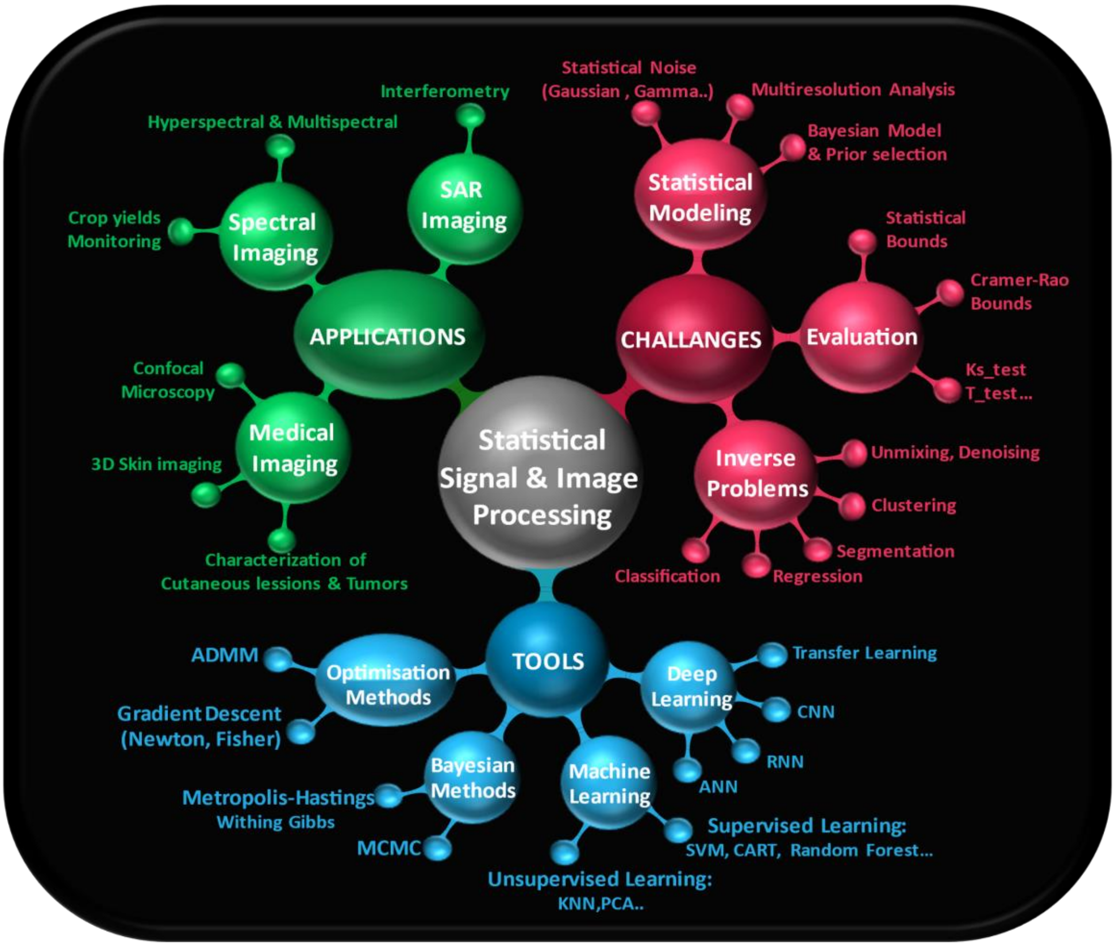


Figure: Descriptive diagram of my research work.

After adopting one of these approaches, the solution of the inverse problem is reduced to the determination of a certain integral (e.g., the MMSE minimum mean square errors estimator) or to the maximization of a criterion (e.g., the maximum a-posteriori estimator (MAP), optimization approach). During my research, I used several methods to solve this task, and they can be grouped into two main families: stochastic simulation methods, and optimization algorithms. In the first family, we find the Markov chain Monte Carlo simulation methods such as the Metropolis-Hastings algorithm, the Gibbs sampler, etc. These latter methods evaluate the a posteriori distribution of the model. These methods evaluate the a posteriori laws of the estimates, and offer the possibility to measure their uncertainties. However, they generally require a rather substantial computation time. The second family includes descent methods such as gradient descent (Natural, Newton-Raphson, etc) and alternating descent. The latter have a more attractive computation time, but they offer a point estimate of the parameters of interest, which is less informative than the stochastic methods.
These theoretical tools are general and can be applied to solve different problems. During my research, I was interested in the following applications: analysis of radar images, hyperspectral images and confocal reflectance microscopy images. These activities were carried out in close collaboration with the National Center for Space Studies and Pierre Fabre Dermo-Cosmetic research center. In the following sections, I briefly describe my research activities for each of these applications.

1. Radar imaging

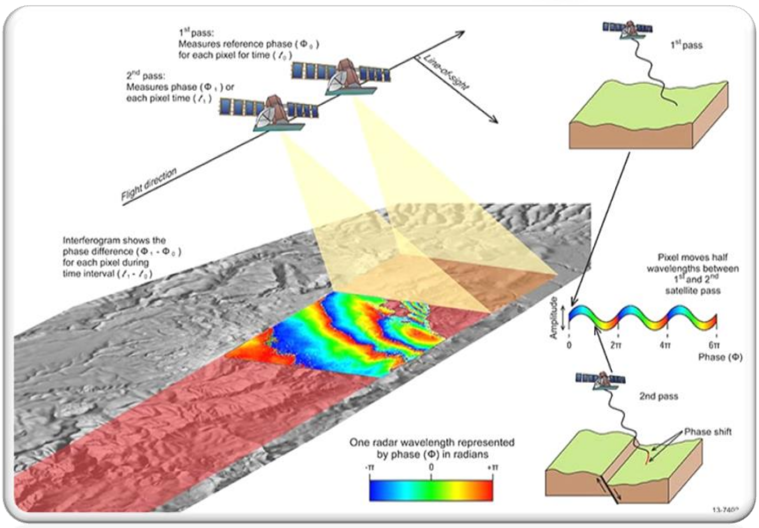
1.1. Introduction

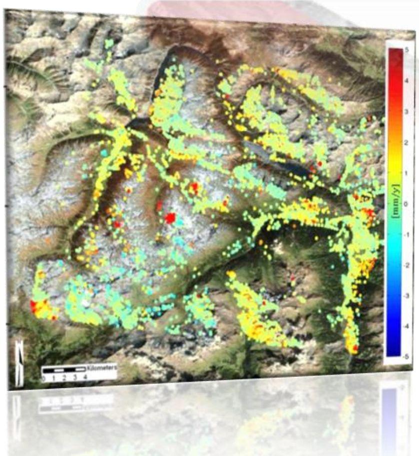
I was interested during my master II internship in radar image processing. The theme of my work was the study of multi-pass differential interferometry and particularly the DInSAR by the Permanent scatters (PS) and its improvement for its use in non-urban areas. The objective was the selection of the distributed scatterers (DS), the construction of groups of this type of scatterers and the optimization of the selection of the representatives of each class in order to establish the differential model for estimating the speed of deformation as well as the phases of errors. This work allowed me to learn about a new area of research and application which is the processing of SAR radar images and particularly radar interferometry (processing of the phase of the radar signal).
On a personal level, this work has allowed me to approach a new line of research whose complexity, throughout the world, is on several levels: the complexity of radar systems, the physics of radar wave-medium interaction, the concepts used, the algorithmic complexity, etc. On the application level, the results obtained complement the work done and still being done at the Image Processing and Radiation Laboratory (LTIR).

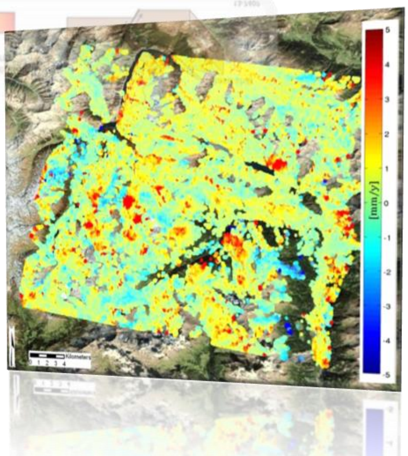
1.2. Interferometry

The interferometric technique was first used for the generation of digital terrain models (DTM), then it was extrapolated for the mapping of ground movements from several images acquired in different dates and this variant is called differential interferometry DInSAR. Their principles exploit the phase difference of two signals acquired by two sensors separated spatially by a distance called baseline by adding in the DInSAR the temporal separation of acquisitions which is translated by the temporal baseline. The constraints related to these two quantities (spatial and temporal baseline) as well as the delay introduced by the atmospheric layer, are the main limitations that have led to the emergence of very advanced techniques to reduce their effects on the accuracy of results. The technique based on permanent scatterers called 'PSInSAR' (Permanent scatterers Interferometry SAR) is one of these new techniques that is very developed for the application of DInSAR in urban environments. However, in non-urban environments, this technique is deficient. In this context, my master's degree project work was mainly focused on improving the technique of PS to make it usable in non-urban environments by introducing the concept of distributed backscatter DS (distributed Scatterers). DS are a set of adjacent pixels with similar statistical characteristics.

In this work, I studied and implemented a DS selection process combined with PS selection for the resolution of the land surface deformation velocity estimation model as well as the topographic and atmospheric errors.







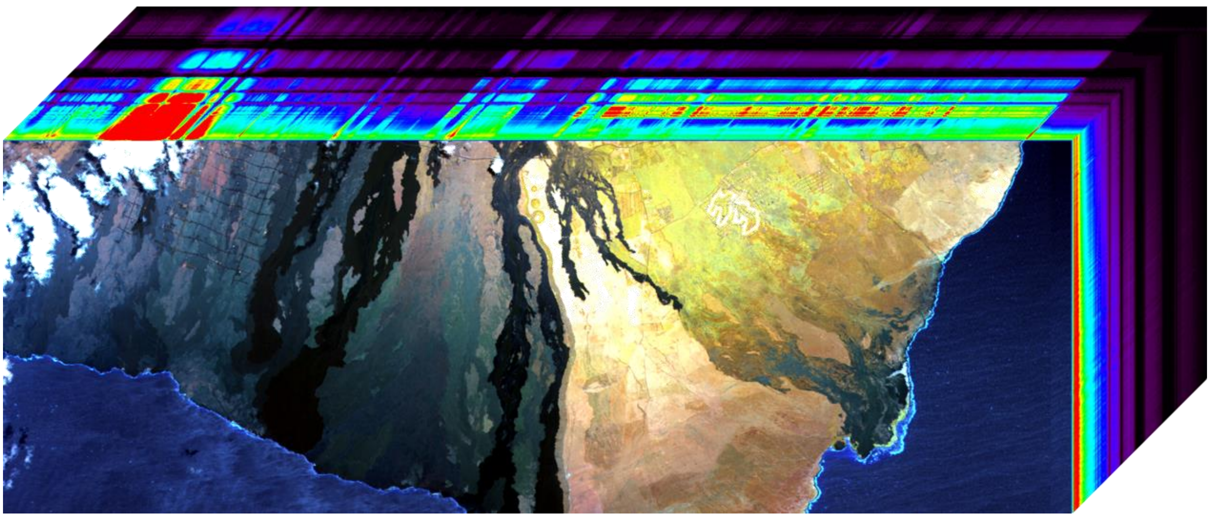
2. Hyperspectral imaging

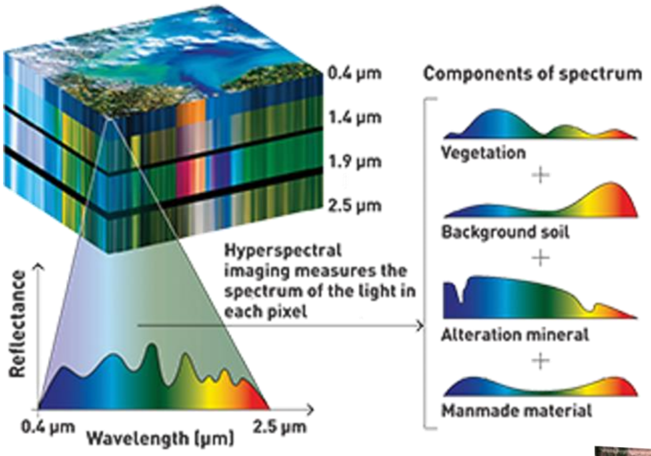
2.1. Introduction

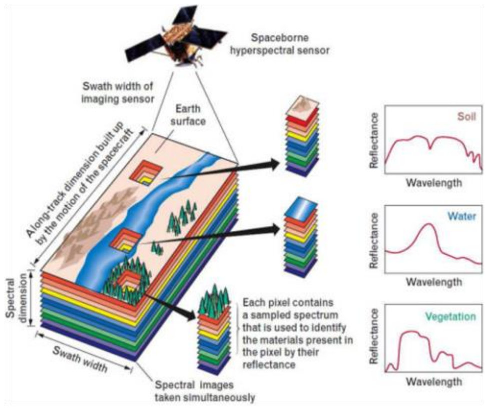
I was interested during my International master internship in the processing of hyperpectral images. The work carried out concerns the linear unmixing of hyperspectral images considering an unsupervised scenario.
A hyperspectral image is obtained by considering the same scene observed at different wavelengths. By grouping all these images, we obtain a data cube that will be used for the analysis. Each pixel of this cube is represented by a spectrum whose number of samples corresponds to the number of wavelengths considered. Because of the low spatial resolution of these images, each pixel is represented by a mixture of several physical materials. The spectral unmixing appears then as a field in full expansion since it seeks to describe the interactions between the constituents of the imaged scene.

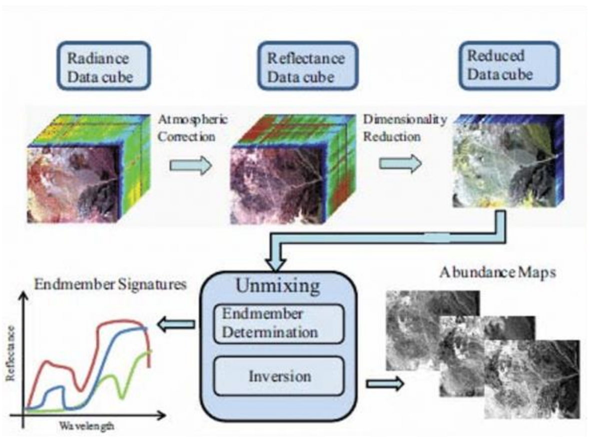
2.2. Bayesian non-parametric approach for linear spectral unmixing

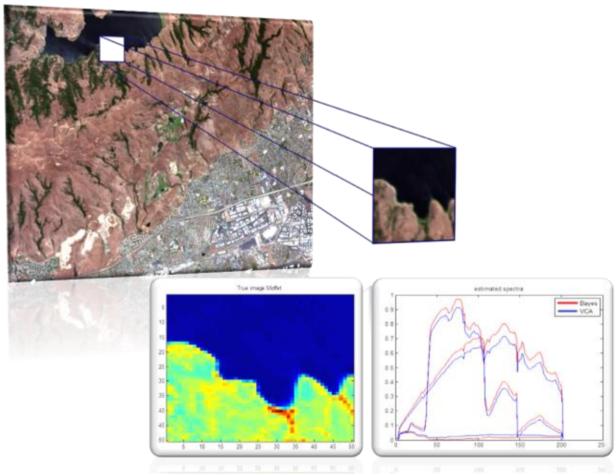
We find several parametric Bayesian methods for linear unmixing in the literature. On the other hand, the number of articles on unmixing with nonparametric Bayesian methods is more limited. The work done during this internship consisted in proposing a new linear unmixing method based on a nonparametric Bayesian method. To do so, I started by studying and applying on synthetic data the different Dirichlet process mixture models (DPMM) using the three processes (Pólya's urn, Chinese restaurant and Indian bullet) that allow us to generate samples according to the Dirichlet process. Then, I chose the most suitable process in order to apply it to hyperspectral imaging for linear unmixing. The proposed algorithm will allow not only the estimation of the parameters (the abundances and the endmembers) but also their number. More precisely, a Gibbs sampler was used to generate samples asymptotically distributed according to the a-posteriori distribution of the different parameters. These samples were then used to estimate the different unknown parameters of the mixture model, via the Bayesian estimators MAP and MMSE. The resulting algorithm was validated on synthetic and real data.











3. Reflectance confocal microscopy imaging

My research in medical imaging was conducted in close collaboration with the Pierre Fabre Dermo-cosmetic research center. The work carried out is mainly interested in the analysis and statistical modeling of reflectance confocal microscopy (RCM) images in order to characterize them for the identification of Lentigo. Reflectance confocal microscopy is an increasingly used medical imaging modality. Indeed, it allows to have a very good resolution of the skin (of the order of µm on the surface and in depth) without altering the skin. Its ease of use and speed of acquisition contribute to the strong development of this tool. However, a long learning curve is required before dermatologists can fully use the possibilities of this technique for diagnostic purposes. This is why more and more methods are used to minimize this learning time by automating some of the steps necessary for diagnosis. In this research, we want to learn how to characterize and distinguish healthy skin from skin affected by lentigo. Lentigos are age spots that appear mainly on the hand or on areas most often exposed to the sun. On the surface of the skin, they appear as a darker spot. Inside the skin, it is mainly at the dermis-epidermis junction that we will see differences. Indeed, the junction is larger and more disordered in an affected area. The motivation of my thesis was to propose statistical models to characterize RCM images to better identify lentigo affected skin from healthy skin. For this purpose, three main contributions have been proposed and described as follows:

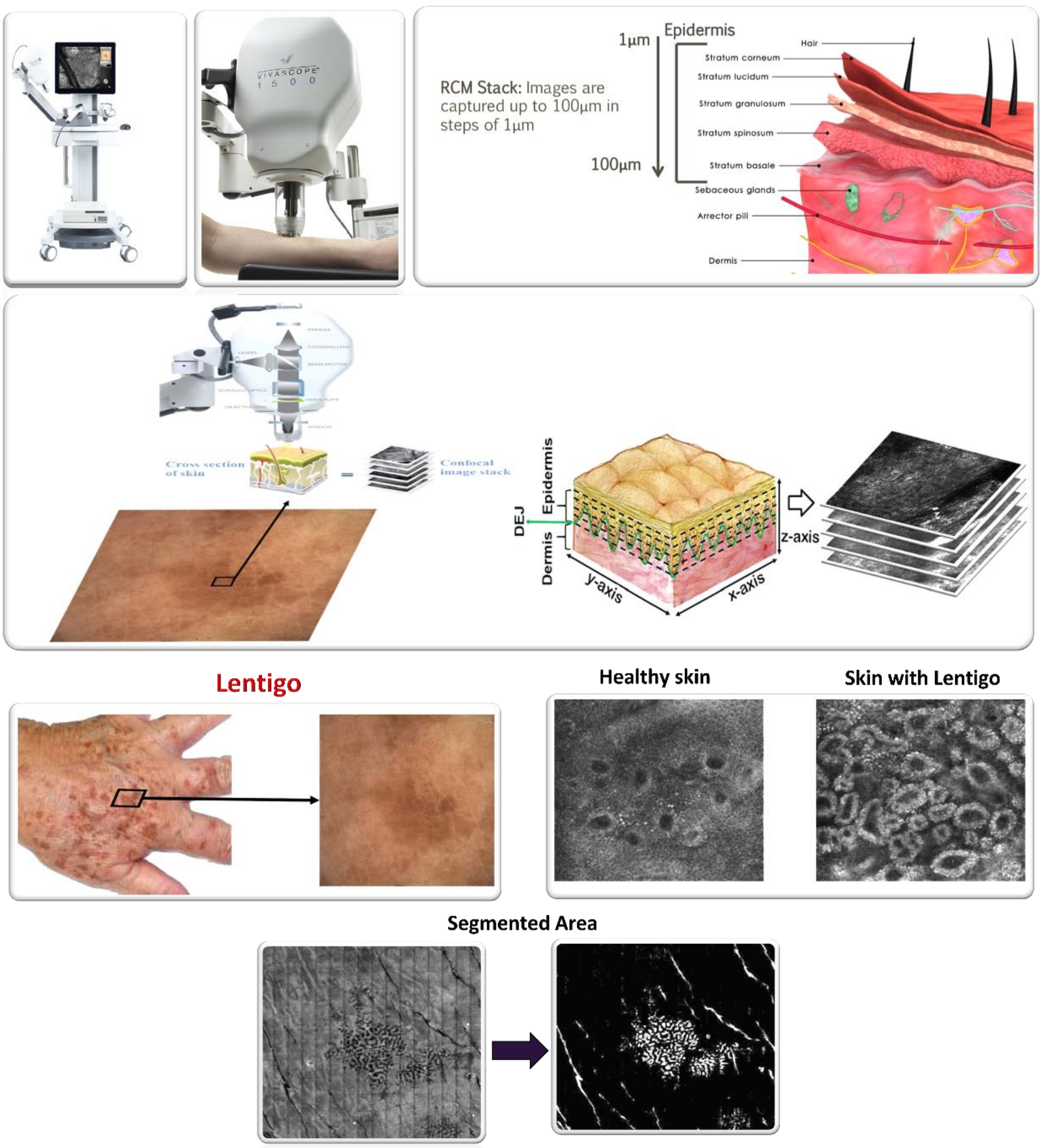
- A first contribution consisted in proposing a parametric statistical model to represent the texture of RCM images in the wavelet domain and then to classify these images into clusters using machine learning techniques. Specifically, it is a generalized

Gaussian distribution whose scaling parameter is shown to be characteristic of the underlying tissue. [Halimi et al, Biomedical optics Express]

- A second contribution consisted in proposing a statistical classification model adapted to the image domain for the characterization of tissues in RCM images using a new fast and robust estimation algorithm for the parameters of the generalized gamma distribution, based on a natural gradient approach. [Halimi et al, CAMSAP]

- A third contribution was to propose a multiplicative noise observation model to explain the generalized gamma distribution of the data. Parametric Bayesian inference methods were then developed with this model to allow joint reconstruction and classification of skin reflectance confocal microscopy images. [Halimi et al, EUSIPCO]

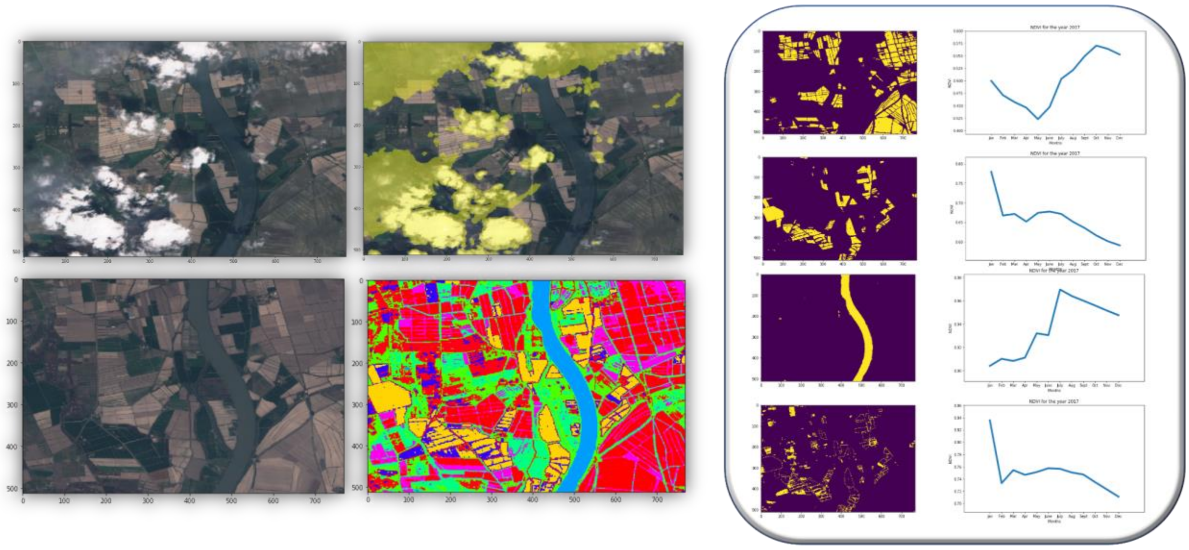
The proposed models were tested on real RCM images collected during a study named cf010 conducted on 50 patient volunteers.



Research & Development Activities

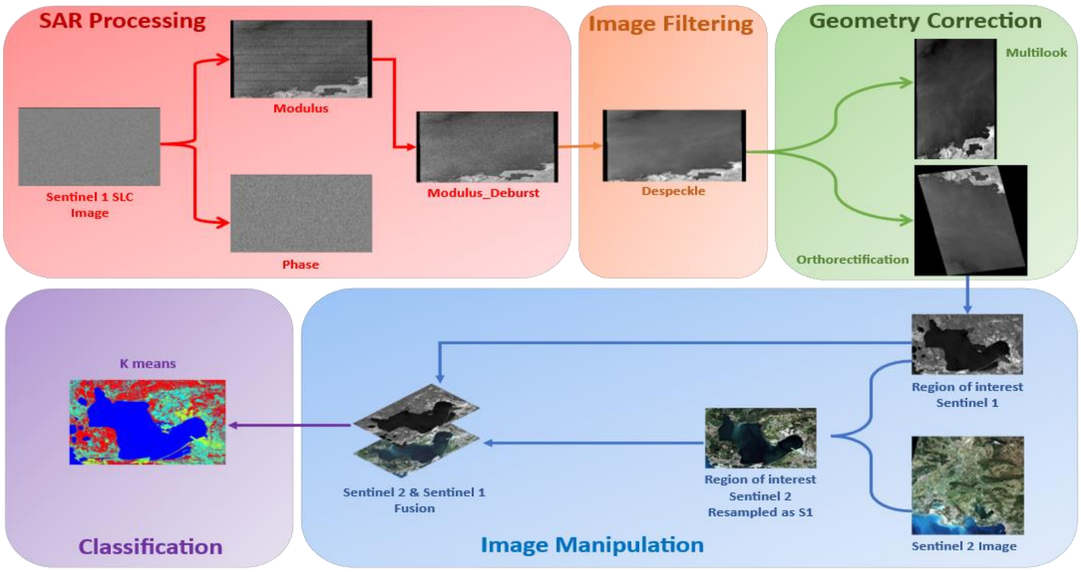
Within the aerospace department, in charge of the development of the platform that manages the access and processing of earth observation data (Mundi Web Services), I proposed and developed several use cases and proof of concept using artificial intelligence and satellite image processing. Among these use cases are the following examples:

- Crop monitoring of the vegetation index via spectral analysis of satellite images
- Cloud detection algorithm for Sentinel 2 images

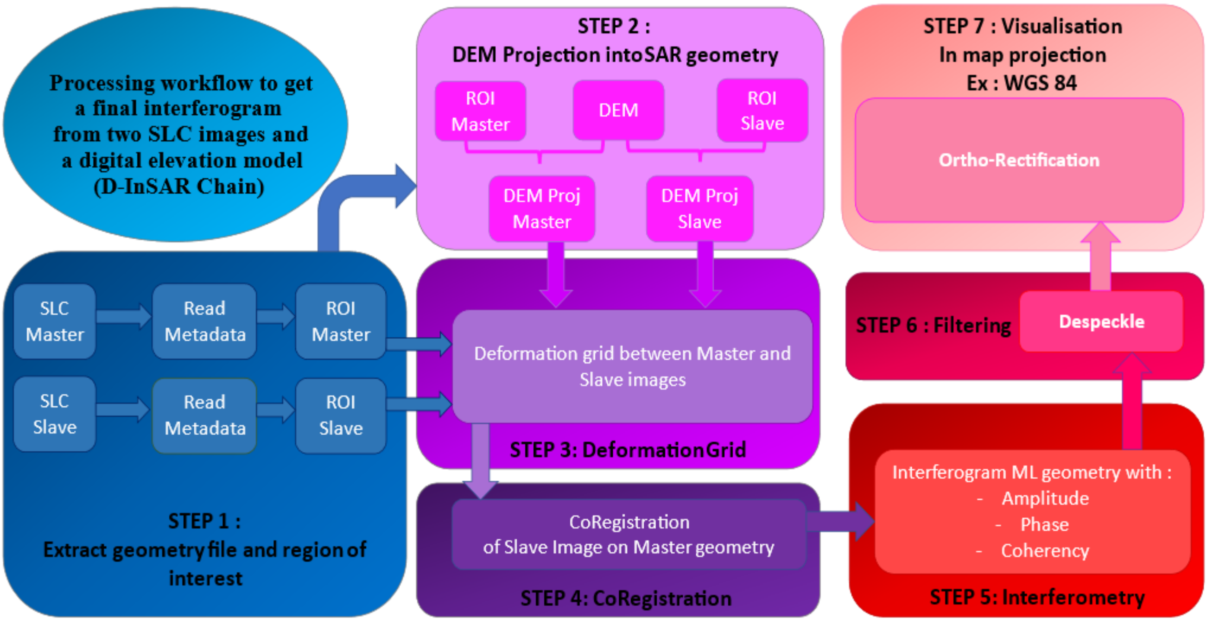


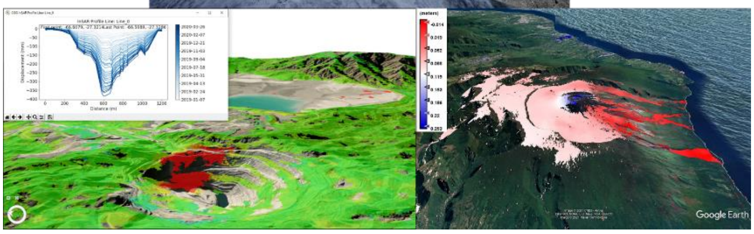
- Pack the OTB (Orfeo toolbox) and SNAP toolbox in a docker image in order to integrate it in the Mundi services platform

- Development of several use cases and tutorials using OTB and SNAP docker images, examples of topics supported:
    - Sentinel-1 and Sentinel-2 data fusion for land classification

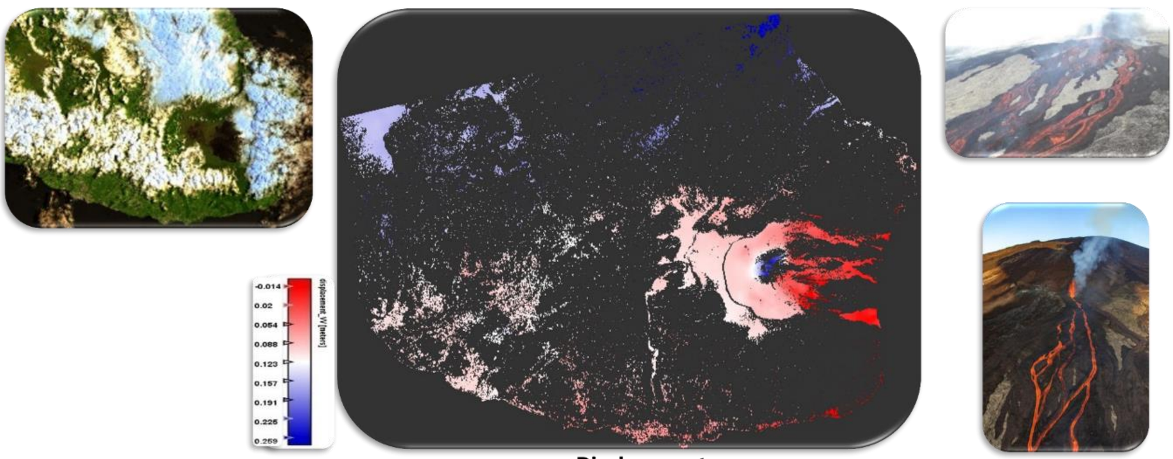


- Proposition of a workflow that allows the analysis of potential events such as earthquakes by highlighting the differences between two SAR images of the same portion of the earth's surface taken at different times using the differential SAR interferometry technique





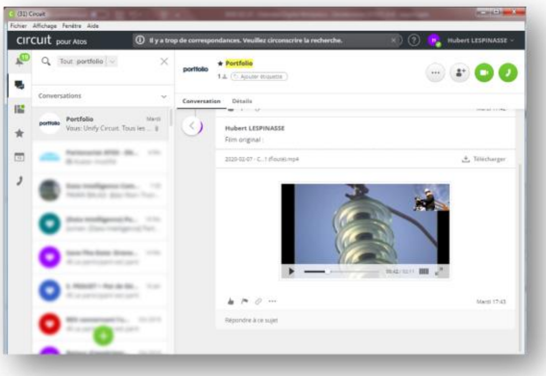
Measurement of the deformations of the Piton de la Fournaise



Displacement
Sentinel-1 (SLC) - (12/2019 and 03/2020)

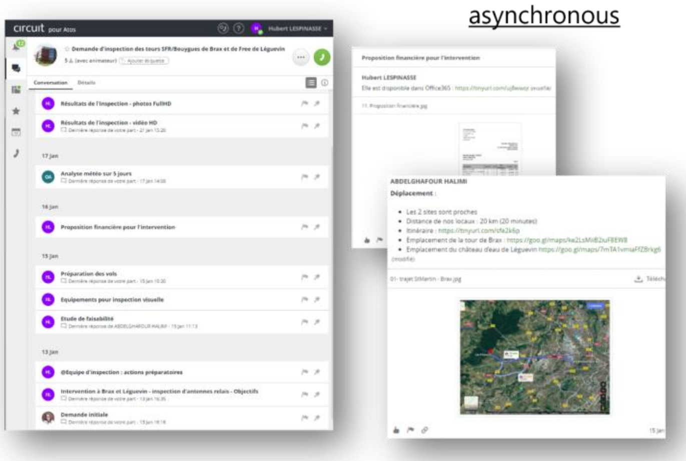
In the research and innovation department at ATOS Toulouse, I proposed and developed several use cases and proof of concept using artificial intelligence and image processing. An example of supported topics is given below:

- **Remote inspection**: Remote inspections can provide easy, real-time access to experts no matter the location. Using a secure, low cost unified communication platform as circuit can provides security and very high-quality video even at very-low bandwidth situations. Circuit's remote inspection involves live-streamed audio-video conferencing as well as advanced functionalities that will assist the inspection process such as document sharing (synchronously and asynchronously), screen captures and annotations or even connecting multiple sensors (drone, Microscope...). An example of a use case that shows us how we can boost the expert productivity using Circuit's remote inspection of an insulator in noisy environment can be seen here

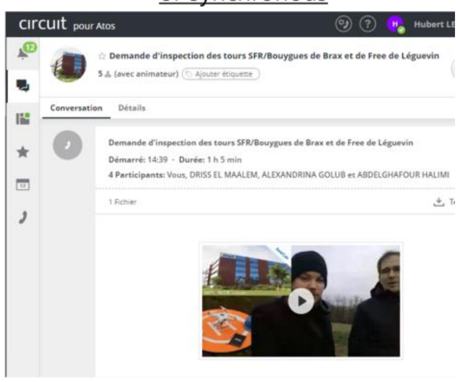


Another example of how Circuit's remote inspection was used is the inspection of a 4G/LTE antenna (a base station), this inspection was carried out using images provided by a drone and transmitted to a remote person who was able to direct all the operations without having left his office. (These examples show us that our proposed method is a good and efficient way for the remote collaboration)

asynchronous

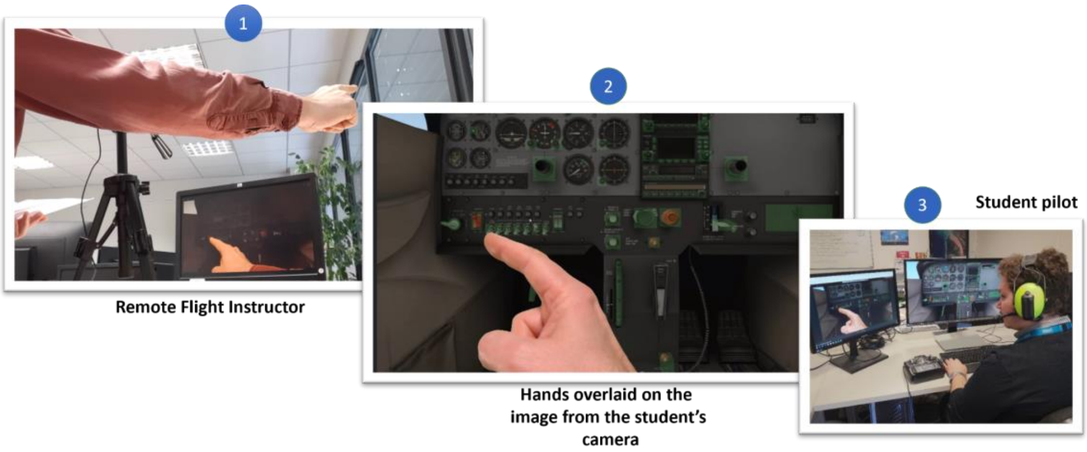


or synchronous



Circuit

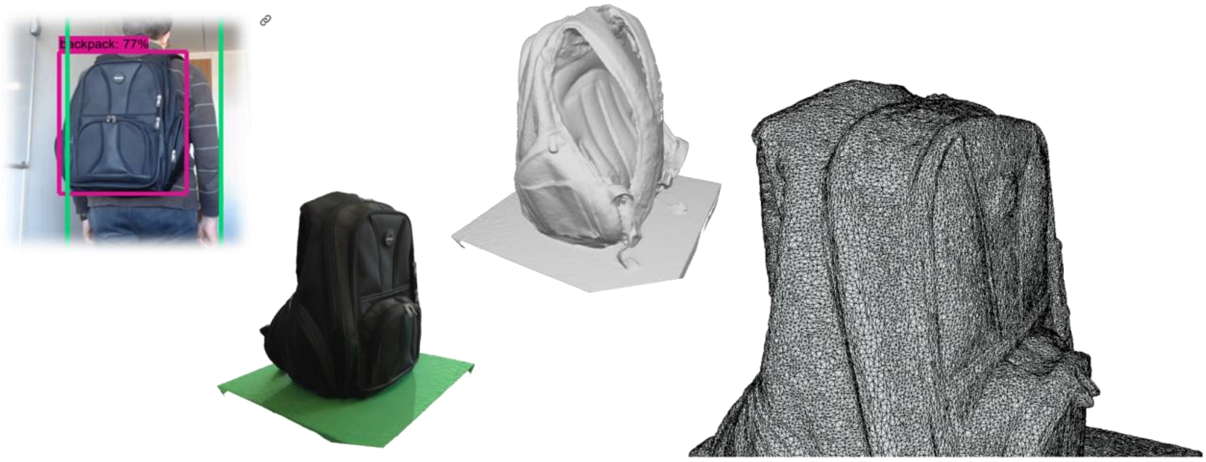
- **Video assistance**: another application where circuit can be useful is the video assistance, To illustrate this point (or proposal), we have done a merged reality demo that consist on starting a cessna 172 with only remote help using circuit video conference, an example of remote flight instructor who gives all the necessary steps (or instructions) to the student pilot in order to start the airplane remotely using the merged reality video-assistance is given below



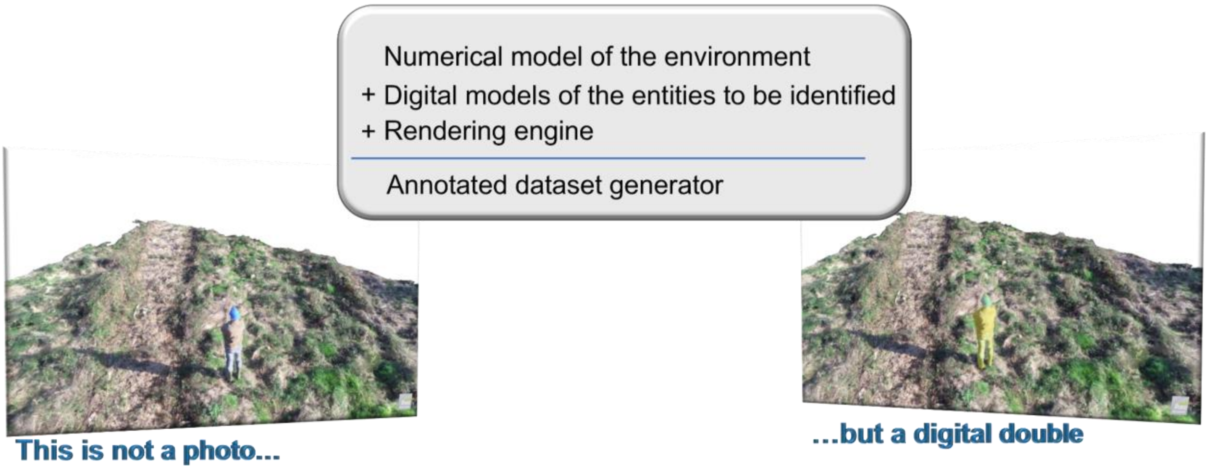
So here we can see that just by adding an image processing step to a simple video conference, we can get a merged reality environment where an expert can assist a technician remotely without relocating. Thanks to the integration of merged reality during a video-assistance session, the expert can now see the technician's workspace in real time, do annotations on the video stream or show them what needs to be performed. With merged reality video assistance, the expert can guide the technician step by step to solve a problem more quickly and efficiently than with normal video solutions.

- **Advanced computer vision**: we was able to go even further and add an artificial intelligence step to this process which will allows us this time to analyses all the images coming from a video conference using a pre trained classifier in order to detect more than 70 classes of different object in real time, an example of some results that can obtained with this classifier is given here

- **3D object reconstruction**: we were also able to reconstruct in 3D the detected object using this classifier as can be seen here below



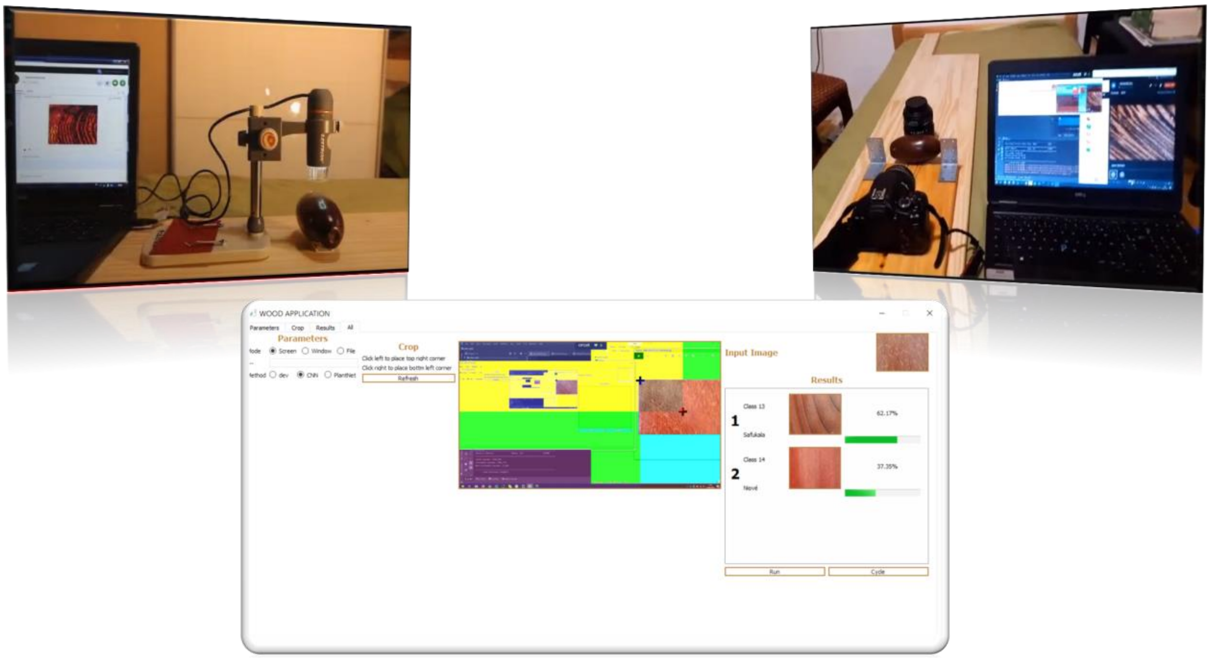
This can be very useful for many applications in a wide variety of fields. For instance, in medical imaging, the lesion information of the patients can be presented in 3D on the computer, which offers a new and accurate approach in diagnosis and thus has vital clinical value. In our case we used this for the virtualized learning in order to contain costs. The realism of these simulations makes it possible to consider doing without the tangible world to produce automatically annotated "datasets" from digital twins as follow



The different offers were presented to the customs then to several customers (Engie, Gendarmerie Nationale, SNCF, Air france), these offers had really interested the industrialists having personnel "outside"

- **Innovation Week**: During 3 days Atos opened an internal TV channel where 350 selected people out of 130 000 employees presented their activities. I was selected among the different speakers on the topic "TELV095 Extended Digital Workplace with Drones, Robots", and I had gain a spot recognition for my work and my presentation during this first Atos innovation week

- **Supervision**
    - Surface inspection with artificial intelligence
    - Targeted tree harvesting (Identification of wood species with artificial intelligence)



Collaborations

Complete list of publications

1.1 International journal papers

1. **A. Halimi**, H. Batatia, J.L. Digabel, G. Josse and J.Y. Tourneret, “ Statistical modeling of reflectance confocal microscopy images and characterization of skin lentigo ” Biomedical Optics Express, 8, 5450-5467 (2017)
2. **A. Halimi**, H. Batatia, J.L. Digabel, G. Josse and J.Y. Tourneret, “ Statistical Model based Classification of Reflectance Confocal Microscopy Images ” Signal image and video processing, Submitted
3. **A. Halimi**, H. Batatia, J.L. Digabel, G. Josse and J.Y. Tourneret, “ Unsupervised Bayesian model for the classification of reflectance confocal microscopy images” IEEE Transactions on Biomedical Engineering, Submitted

1.2 International conference papers

1. **A. Halimi**, H. Batatia, J.L. Digabel, G. Josse and J.Y. Tourneret, “ An unsupervised Bayesian approach for the joint reconstruction and classification of cutaneous reflectance confocal microscopy images ” 25th European Signal Processing Conference (EUSIPCO), Kos island, Greece, pp.251-255, 2017.
2. **A. Halimi**, H. Batatia, J.L. Digabel, G. Josse and J.Y. Tourneret, “ Statistical modeling and classification of reflectance confocal microscopy images ” Computational Advances in Multi-Sensor Adaptive Processing Conf. (CAMSAP), Curaçao, Dutch Antilles 2017

1.3 Thesis and Master II

1. **A. Halimi**, “Modeling and statistical processing of confocal microscopy images: application in dermatology,” Ph. D. dissertation, INPT-ENSEEIHT, Toulouse, France, Décembre 2017.
2. **A. Halimi**, “Bayesian Nonparametric Methods : application to hyperspectral imaging,” Master’s thesis, INPT-ENSEEIHT, Toulouse, France, July 2014.

1.4 Technical reports

1. **A. Halimi**, H. Batatia, J. L.Digabel, G. Josse, and J.-Y. Tourneret, Technical report associated with the paper “ An unsupervised Bayesian approach for the joint reconstruction and classification of cutaneous reflectance confocal microscopy images ”, University of Toulouse, France, Tech. Rep., Feb 2017. [Online].
Available : https ://arxiv.org/pdf/1703.01444.pdf
2. **A. Halimi**, H. Batatia, J. L.Digabel, G. Josse, and J.-Y. Tourneret, Technical report associated with the paper “ Statistical modeling and classification of reflectance confocal microscopy images ”, University of Toulouse, France, Tech. Rep., April 2017. [Online].
Available : https ://arxiv.org/pdf/1707.00647.pdf
3. **A. Halimi**, H. Batatia, J L.Digabel, G. Josse, and J.-Y. Tourneret, ’Technical report associated with the paper “ Wavelet-based statistical classification of skin images acquired with reflectance confocal microscopy ”, Tech. Rep., University of Toulouse, France, Feb 2017.