Morphological characterization of *full waveform* airborne LiDAR data

Context

This PhD thesis aims at exploring the potentialities of *full waveform* LiDAR data to finely characterize observed structures. To this end, we plan to explore morphological multi-scale approaches. The methodological developments will be applied to vegetation characterization in urban areas.

The main principle of remote sensing LiDAR is to send a laser pulse from a transmitter and to analyze the backscattered signal (in particular its largest amplitude) to reconstruct the 3D position of the encountered objects (to which the intensity of the wave is generally associated). Using airborne LiDAR, it is possible to obtain a series of 3D positions whose analysis is extremely interesting to characterize the observed scene (see e.g. Rottensteiner and Briese, 2002 in an urban context).

The most recent works aim at studying the *full waveform* backscattered signal: the analysis is no longer limited only to the peak of the backscattered laser, but is performed on the entire signal. Depending on the wavelength of the emitted laser pulse (and therefore its ability of penetration in certain materials such as vegetation), it is then possible to find, in addition to the coordinate of the first encountered point, all the obstacles located along the signal path. This is of prime interest, especially for the analysis of vegetation, since it allows accessing not only the *envelope* of the species encountered but also their *dense* structure. For these reasons, the Observatories of Universe Sciences (OSU) of Nantes and Rennes bought a *full waveform* LiDAR in 2015 and several acquisitions on these two cities, in winter and summer, are today available. However, such observations are still not fully exploited because of the lack of methodological tools to analyze the amount of the available data.

Indeed, few techniques exist today to finely characterize point clouds and their distributions, especially to extract vegetation. Although efficient methods for characterizing LiDAR data exist (such as CANUPO developed at Rennes's OSU), they do not sufficiently take into account the geometrical and multi-scale aspect of the structures. In this thesis, we propose to exploit tools from multi-scale morphological analysis to address this issue.

PhD topics

Scientific issues:

In this PhD, approaches based on mathematical morphology will be exploited. Mathematical morphology offers a methodological framework and a rich set of algorithms for the analysis and processing of images. Morphological approaches have been used successfully in many fields, and their relevance in remote sensing has no longer to be demonstrated (Soille and Pesaresi, 2002, Marcotegui, 2015).

Scientific approach:

In particular, we plan to rely on morphological representations based on trees (such as the *max/min-tree*, *tree of shapes, binary partition tree*, *alpha/omega-tree*) because of their ability of multi-scale analysis of massive and complex data. However, the analysis of LiDAR data by such approaches remains very recent and few explored.

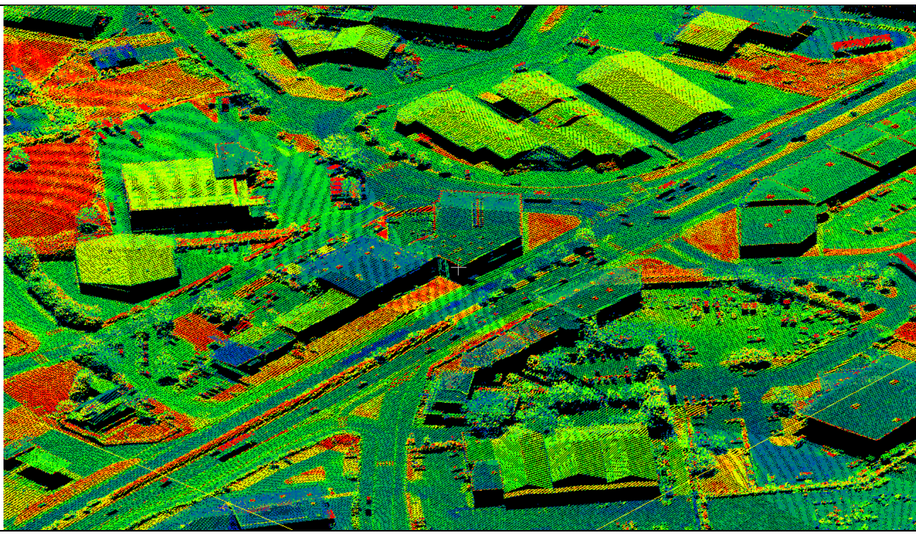
The strategy will consist in producing a multi-scale segmentation and thus constructing a tree representation (using existing tools such as BPT or HSEG algorithms) to extract the characteristics of the image through the information contained at different scales (Tochon et al., 2015, Jung et al, 2015). Today the morphological processing of LiDAR data, when not based on segmentation hierarchies, requires a preliminary transformation of the point cloud into a numerical elevation model on which the morphological filters are applied, before performing an inverse transformation to obtain the resulting cloud (Serna et al, 2014). Although suboptimal, this approach is still possible in "classic" LiDAR (where only backscattered peak is used) but this is no longer possible with full waveform points. The application of morphological operators directly on such a point cloud requires new theoretical and/or methodological developments, such as those recently proposed in (Calderon and Boubekeur, 2014) and (Angulo, 2015). However, the relevance of these solutions in the field of LiDAR remains to be demonstrated and, on the other hand, none of these methods is suitable for *full-waveform* LiDAR. The extension of these approaches and the development of new morphological methods for the analysis of a cloud of dense points will be the main methodological aspects of this thesis.

The application framework is related to the analysis of vegetation in urban areas. Indeed, a very precise nomenclature (ca. 20 classes) of the different vegetation types that appear in urban environment (e.g. wooded and aligned leafy, vegetal roofs, herbaceous paths, sports equipment, etc.) is nowadays available (Nabucet et al., 2015). However, only 5-6 classes of vegetation can be identified using satellite imagery because of the lack of spatial and spectral accuracy offered by these data. Indeed, existing works using very high spatial resolution images are usually limited to the extraction of tree or herbaceous vegetation but do not provide information on species, management mode and height (Pu and Landry, 2012, Puissant et al., 2014, Ramdani, 2013, Tigges et al., 2013). This fine characterization is however required in many contexts, e.g. to model the circulation of animal species through vegetated spaces (the nature of the elements in urban vegetation can be both an obstacle for species and a link for them, see Croci et al., 2008) or to analyze the impact of green surfaces on local climate (Foissard et al., 2014). Thus, we propose in this work to analyze the potentialities of the LiDAR data to characterize as precisely as possible the different species.

Data and equipment

The developed methods will be applied to data acquired on the cities of Nantes and Rennes and the software tools will be integrated into existing platforms (CloudCompare, Orfeo, LiDAR-plateform in Rennes, LOVE plateform in OSU of Rennes). Although applied here to urban vegetation, these methods will remain generic and can be used to characterize 3D data in other contexts.

As for LiDAR acquisitions, at the moment two sets of *full waveform* LiDAR data on cities of Rennes and Nantes are available (a third one is expected in winter 2017). We are also planning an acquisition in a subarea of Rennes with airborne measurements at several altitudes (from 200m to 1200m) to assess the capabilities of the methods developed in this doctoral project for identifying vegetation with data of various quality. An example of a LiDAR scan on Rennes is shown in the figure below.



Example of LiDAR data. Here only the peak is plotted but at each point is associated a distribution. It is therefore necessary to be able to automatically classify all these points

Practical information

This PhD will be supervised by Thomas Corpetti (DR CNRS, OSU / LETG-Rennes COSTEL; http://www.sites.univ-rennes2.fr/costel/corpetti) and Sébastien Lefèvre (Prof. Univ. Bretagne Sud, IRISA Vannes, OBELIX team; people.irisa.fr/Sebastien.Lefevre) and will take place in the context of the IRISA OBELIX team (www.irisa.fr/obelix).

Laboratory: LETG-Rennes COSTEL, with regular visits to IRISA Vannes (team OBELIX).

The candidate must have a background in applied mathematics and / or signal processing and / or computer science.

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