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# Use of Airborne LiDAR data processing tools and algorithms in natural forested areas: A systematic review

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LiDAR (Light Detection and Ranging) systems such as ALS (Airborne Laser Scanning) are increasingly being used in studies that analyse the forest structure and for the characterisation of their ecosystem processes. The main reason is their ability to provide an accurate three-dimensional description of the canopy structure, compared to other existing methods, such as passive sensors or photogrammetry. In addition, the high positional accuracy of ALS and their capacity of penetrating the canopy through small gaps in the forest canopy allow the estimation of parameters such as aboveground biomass, vegetation height, or leaf area index, among others. In forestry applications, the acquisition of these parameters usually requires a pre-processing analysis of the point clouds, which includes ground point filtering, Digital Terrain Model (DTM) and Canopy Height Model (CHM) derivation, tree detection, and segmentation, among other processes. In the last decades, point cloud processing has benefited by the development of dedicated software packages such as LAStools, FUSION, or Terrascan, focused on obtaining DTM/CHM and LiDAR-derived metrics. However, the recent development of more sophisticated software packages, such as LidR or Pycrown, allow implementing novel and state-of-the-art algorithms as well as specific user-created functions.

The wide variety of licensed and open-source software packages for ALS data processing, together with the increasing diversity of existing algorithms and methodologies, has provoked a multitude of comparative analysis of the most widely used algorithms in the scientific literature. However, given the recent development of the field, a robust and exhaustive review of the current use of these software and the related algorithms is still missing. In this contribution, we present a synthesis review of 613 papers on the use of software packages and algorithms for ALS processing used between 2016 and 2020. The review focuses in forest environments with a complex structure where the difference in elevation, slope, and the existence of multiple vegetation strata usually requires more complex and specialised algorithms. Therefore, three specific steps of LiDAR processing workflow were considered: ground point filtering, DTM interpolation and crown detection and segmentation. The results showed that ground point filtering (84% of the studies) is the most common step in ALS processing, compared to DTM interpolation (71%) and tree segmentation (36%). For the DTM interpolation step, TIN construction was the most used method (13%) compared to other methods such as ordinary kriging (3%). Conventional software packages

that employ algorithms based on progressive TIN densification or hieratical robust interpolation approaches were the most commonly used in ground point filtering for DTM generation. Meanwhile, other user developed advanced algorithms were used more frequently in canopy segmentation processing, especially in those articles using datasets with high point densities (165.93 p/$m^2$ on average), compared to datasets processed with more general software solutions as FUSION (13.81 p/m2).