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Fusion of LiDAR and hyperspectral imaging for forest applications

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Effective strategies for forest characterization and monitoring, are important to support sustainable management. Recent advances in remote sensing, like LiDAR and hyperspectral sensors, provide valuable information to characterize forests at stand, plot and tree level. LiDAR data offers potentialities for analyzing structural properties of canopy, while hyperspectral imaging contains meaningful reflectance attributes of plants or spectral traits. The fusion of these two modalities provide better and more robust estimation of the forestry variables. This work presents a review of methods for the integration of LiDAR data and hyperspectral imagery by taking into account applications related to forestry. Although different authors propose different approaches of data fusion, our review is divided according to three levels of fusion based on data processing: observation level, feature level, and decision level. Fusion at observation level preserves most of the original information from both modalities by integrating 3D point cloud with the hyperspectral information. One alternative for this task is the generation of the Canopy Height Model (CHM), which is the most used two-dimensional representation of LiDAR data. Fusion at feature level seeks to complement information by exploiting the original data. The most relevant features extracted from LiDAR or hyperspectral data are statistical, structural, topographic, vegetation indices, textural and dimension reduction. Some of these feature descriptors are stacked to be fused at higher level, or these are normalized to be integrated through methods of dimension reduction or feature selection. Fusion at decision level is directly associated to the forestry application and implies tasks of segmentation, classification, data association and prediction - estimation. This review describes relationship between the three levels of fusion and the methods used in each considered approach. The most important applications are oriented to species mapping, functional and physiological attributes, structural attributes, above ground biomass and carbon density and landcover maps.