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Review

Airborne laser scanning of forest resources: An overview of research in Italy as a commentary case study

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ABSTRACT

This article reviews the recent literature concerning airborne laser scanning for forestry purposes in Italy, and presents the current methodologies used to extract forest characteristics from discrete return ALS (Airborne Laser Scanning) data. Increasing interest in ALS data is currently being shown, especially for remote sensing-based forest inventories in Italy; the driving force for this interest is the possibility of reducing costs and providing more accurate and efficient estimation of forest characteristics. This review covers a period of approximately ten years, from the first application of laser scanning for forestry purposes in 2003 to the present day, and shows that there are numerous ongoing research activities which use these technologies for the assessment of forest attributes (e.g., number of trees, mean tree height, stem volume) and ecological issues (e.g., gap identification, fuel model detection). The basic approaches – such as single tree detection and area-based modeling – have been widely examined and commented in order to explore the trend of methods in these technologies, including their applicability and performance. Finally this paper outlines and comments some of the common problems encountered in operational use of laser scanning in Italy, offering potentially useful guidelines and solutions for other countries with similar conditions, under a rather variable environmental framework comprising Alpine, temperate and Mediterranean forest ecosystems.

Contents

1. Introduction

The increasing availability of data derived from Airborne Laser Scanning (ALS) offers the potential to use this three-dimensional

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(3D) information, alone or in combination with satellite multispectral images, to automatically and accurately predict forest characteristics (e.g., tree height, single tree detection, stem diameter, basal area, stem volume, structure, biomass, carbon stock, etc.). The growing interest in ALS resides in the fact that this technology provides true 3D data of both the ground and canopy. Compared with traditional methods used to assess forest attributes (comprising field inventories and conventional remote sensing techniques like photogrammetry), ALS data are more accurate, easy to process automatically and economically attractive (Eid et al., 2004; Holmgren, 2004; Næsset, 2002, 2005a, 2007, 2011). Furthermore, ALS data can even provide additional attributes not retrievable by conventional (optical) remote sensing (Gobakken and Næsset, 2005). Forest structure is a three-dimensional characteristic, comprising the lateral as well as the vertical distribution of the vegetation above the ground. Passive optical sensors are much less sensitive to vertical canopy structure inside the crowns canopy than LiDAR (Light Detection And Ranging) instruments. One reason for this is that passive sensors only provide 3D data from areas in the forest canopies that are visible from more than one sensor position and that scatter back the sunlight. On the other hand, LiDAR is a range resolved technique, that gives for each emitted laser shot information on the distance to the backscattering objects, i.e. the canopy and understory elements, within the beam diameter. Thus, in comparison to traditional photogrammetry ALS offers new ways of describing the forest structure in 3D since this active remote sensing technique can measure the location of objects in 3-dimensional (x, y and z) inside the canopy. The emitted laser pulse strikes a target surface (e.g., ground and vegetation) and returns a portion of the laser energy to the sensor. The elapsed time between pulse emission and detection produces the round-trip distance between the sensor and target, and the vertical distribution of surfaces is recorded using either discrete point-by-point (discrete point return system) or continuous data (continuous “waveform” systems). Discrete return ALS systems were developed over the last 20 years for mapping terrain purposes (Wehr and Lohr, 1999). These systems may be further divided in single-returns systems or in multiple-return systems if the device records a single (first and last) or multiple returns (generally five or fewer) from a given laser pulse. First-return records the height of the first object in the path of the laser pulse, whereas last-return records the height of the last object illuminated by the laser pulse. In the multiple-return systems the pulse is not completely blocked when it strikes a target, and the remaining portion of the pulse continues to the lower object (Reutebuch et al., 2005). In contrast, waveform systems digitize the entire reflected energy from each laser return, providing a record of the height distribution profile of the surfaces illuminated by the laser pulse (Harding et al., 2001).

A survey carried out with an airborne laser sensor over a forested area produces a three-dimensional cloud of points, used to characterize forest attributes through appropriate statistical relationships between field data and ALS data, and these relationships can be used to predict corresponding properties in all forest stands in an area. There are two broad categories of ALS data analysis approaches to support forest inventory and management: area-based approaches (AB), also called statistical canopy height distribution approaches, and individual tree crown (ITC) approaches. In the AB approaches, stand biophysical attributes are estimated by relating plot level data to ALS data which have been aggregated at plot level; AB approaches relate Canopy Height Model (CHM) raster pixels or point ALS data to measured plot characteristics in order to build parametric (e.g., regression) or non-parametric models to predict forest attributes. Collective biophysical attributes are considered over plots ranging from hundred up to thousand square meters; the established models have been shown to explain the majority of variation in stand height, volume, biomass, and basal area. The ITC approaches include all the methods based on the detection of individual trees in a given forest stand. ITC approaches may use both a raster CHM and point ALS data to build polygons for individual tree crowns and/or 3D tree profiles; these individual tree records can then be aggregated to any scale required to create stand level estimates. AB and ITC approaches for the estimation of biophysical attributes are not mutually exclusive and can be combined (e.g., Lindberg et al., 2010; Vastaranta et al., 2012).

During the last twenty years, there has been a great deal of research activity on ALS-based forest inventories in different parts of the world. As reported by Næsset et al. (2004), the first published study to estimate tree height with a profiling ALS was conducted in the Soviet Union (Solodukhin et al., 1977), soon followed by similar studies in North America (Aldred and Bonnor, 1985; Maclean and Krabill, 1986; Nelson et al., 1984). In Europe, the first applications of ALS for retrieval of forest attributes were conducted in the Nordic countries (Næsset, 1997a,b; Nilsson, 1996, 1994; Hyyppä and Inkinen, 1999); currently the use of ALS data is becoming a dominant forest inventory method in Norway and Finland.

To obtain a summary on the laser scanning experience in several countries (e.g., Nordic countries, USA, Canada, and Australia) the reader is referred to Holmgren (2004), Hyyppä et al. (2003, 2008, 2009), Leeuwen and Nieuwenhuis (2010), Lefsky et al. (2002), Lim et al. (2003), Maltamo et al. (2007), Næsset (2003), Næsset et al. (2004), Nilsson et al. (2003), Turner et al. (2011), and Wulder (2003).

The use of ALS data has recently by applied for numerous purposes in Italy. For this review we identified 23 papers, with an increasing number of papers in 2011. This increasing trend is expected to grow, making this a critical time for a review of the existing work. The papers included a range of ALS application domains, methods, and sensor types. Retrieval of forest attributes (at plot or stand level) is a predominant application, especially in the Alpine area. There is some limited interest in ecological issues and no study was found using change detection, although this is expected to increase significantly with the availability of new ALS data.

This article is conceived as a scientific commentary review and selective discussion about ALS-based forest applications in Italy, with special consideration to common problems in the operational use of ALS systems. The case studies presented here offer potential guidelines and solutions that may be useful to other countries with conditions similar to Italy, under a rather variable environmental framework comprising Alpine, temperate and Mediterranean forest ecosystems.

2. Airborne Laser Scanning survey experience in forestry applications in Italy

In Italy, ALS research for forestry is relatively recent since the first studies using ALS data were conducted around 2003–2005 by Barilotti et al. (2005a,b). In 2003 and 2004, Barilotti et al. (2005a) used first and last pulse ALS data from an Optech ALTM 3033 laser scanner to develop and test automated detection methods for individual trees in coniferous-dominated and mixed forest sites in mountainous areas of Friuli Venezia Giulia (Northeastern Italy). The first area was surveyed in September 2003 with a mean laser point density of 2 points/m^2, while the mixed forest was surveyed in July 2004 with a mean density of 4.3 points/m^2. The method was tested on a Digital Surface Model (DSM) which provides a measure of the height of the surface surveyed plus the height of the Digital Terrain Model (DTM, also called Digital Elevation Model or DEM). The DSM raster had a 1 m pixel resolution. The results of this study showed that the coniferous site had a tree detection error of less than 20%, except for two high density plots. The error was