LINHE Project: development of new protocols for the integration of digital cameras and LiDAR, NIR and Hyperspectral sensors

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Abstract

The LINHE project aims to develop applications for forest management based on the combined use of LiDAR data, images from spaceborne (multi and hyperspectral) and airborne sensors (panchromatic, colour, near infrared), and NIR field data from a portable sensor. The integration of the different types of data should be performed in a rapid, intuitive, cost-effective and dynamic way. In order to achieve this objective, new algorithms were developed and existing ones were tested, for the correlation of data collected in the field and those gathered by the different sensors. Specific software (LINHE prototype viewer) was developed to support data gathering and consultations, and it was tested in three different forest ecosystems, so as to validate the tool for forest management purposes. The optimisation of the synergic capabilities derived from the combined use of the different sensors will allow the enhancement of their efficiency and provide accurate information for operational forestry.

Keywords: LiDAR, Digital photogrammetric Camera, hyperspectral spaceborne sensors, land NIR sensor, forest inventory

1. Introduction

The use of LiDAR (Light Detection and Ranging) technology in different forestry applications is a research line in which universities, technology centres and private companies are currently involved. Commonly, research in LiDAR topics is mainly focused on developing algorithms able to analyse the vast quantity of data gathered. These algorithms (or filters) aim to obtain different digital elevation models of the terrain and of objects attached to and detached from it. Most of these filters were tested and analysed in Sithole and Vosselman (2003). ALS (Airborne Laser Scanning) provides information about forested areas by a direct quantification of certain forest parameters such as tree height (Hyyppä et al 2005; Pearsson et al 2002; Popescu et al 2002; Riaño et al 2002) or density related variables as the penetrability index (Morsdorf et al 2005; Riaño et al 2004), and biomass products (Lefsky et al 1999) as forest fuels, carbon sequestration or leaf area index (Roberts et al 2005). Measuring the backscattered intensities of the laser pulses at different heights allows studying the vertical stratification of the canopy cover at a stand level. However, works on LiDAR data applications for forest inventory, such as forest stand control and assessment (Næsset et al 2004; Parker et al 2004), are scarce.

The optimization of the synergic capabilities derived from the combined use of different types of sensors enhances their efficiency by providing accurate information which can be very useful for operational forestry. This approach allows, for instance, adjusting the relationship between altimetric LiDAR information and individual trees of the forest stand. Even more, it allows relating accurate estimates of sub-stand parameters, i.e. crowning dimensions, height and diameter at breast height or *DBH* (Hyyppä and Inkinen 1999), with stand density -by means of canopy detection algorithms-, and structure -by mapping the spatial distribution of dominance and canopy gaps. LiDAR may benefit from image support (Riaño et al 2007; StOnge et al 2001), supplied by video film or by a conventional photogrammetric camera, in order to establish structures. Although it has been hinted that the intensity of the return may provide information about structures, the necessary software has yet to be developed, and at this point this line of research is still at an academic level. Moreover, digital cameras offer RGB colour, panchromatic and infrared images as georeferenced digital products. Combining ALS and photogrammetric data, simultaneously obtained using the same aerial platform, might enhance the possibility of gathering information from ecosystems by adding biological and physical environmental features to the metric parameters obtained by laser.

Additional information captured by other sensors (mid-infrared sensors, near infra-red -NIR- and/or visible spectrum) aids the classification of LiDAR data and it is eventually used to expand the range of predictions across those areas where the use of LiDAR will be too expensive or unfit for the estimation of other valuable information (species distribution, tree health or phenological stage). The infrared spectrum has been traditionally used to evaluate vegetative stages of plants, assess fire damage, track the evolution of pests or pathologies, etc. Combining several sensors offers the advantage of obtaining different kinds of data during the same flight (the principle of capture once and use several times…), although it also poses multiple technical problems yet to be resolved. On the other hand, the possibility of obtaining thematic cartography in real time is opened. "Real time mapping" is currently receiving much attention as will drastically reduce the production cycle (in hours or days) and therefore the production costs.

Hyperspectral images are ideal tools for environmental applications. Fine spectral resolution is important for the discrimination of certain features such as vegetation health or distribution, which can be difficult to detect with medium resolution optical systems or commercial aerial photography configurations. Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. Hence, a characteristic spectral signature can be used for the identification of vegetation types or conditions. The level of resolution of those images offers a local improvement to the use of medium resolution optical from satellite platforms since it can provide a better definition of the relationships between stand structure (stand density or canopy cover) and reflectance. This provides more flexibility in terms of data acquisition, and improves the chances of getting cloud free images. Furthermore, they can provide the sampling material for extending predictions over large areas using cheaper data such as satellite images or thematic layers in a software GIS.

2. Project description and objectives

This paper intends to be a brief description of the LINHE project. The project aims to design and develop a framework (LINHE tool) able to integrate and analyse georeferenced data in order to set up viable and operational applications for forest management purposes. The LINHE tool for forest management consists on a set of procedures and utilities, including techniques for processing and analysing the different data types, the methodologies employed for data acquisition and a prototype viewer. LiDAR data, images from spaceborne (multi and hyperspectral) and airborne sensors (panchromatic, colour, near infrared), and NIR field data from a portable sensor were handled, as well as field measurements and estimations of different forest parameters. The LINHE tool is intended to allow the integration of data in a rapid, intuitive, cost-effective and dynamic way. In order to achieve this objective, it was proposed to implement new algorithms and to test existing ones dealing with data correlation.

The project proposes a methodological model to apply the mentioned technologies to the improvement and sustainability of forest management, dealing with and taking advantage of the different spectral, temporal and spatial resolution offered by the sensors. In order to design a system capable of monitoring both high and low frequency changes in forests, a cross spatial and temporal resolution system must be established, using data from multiple satellite and in-situ data sources. As a consequence, gaps and overlaps in earth observation data, ground systems, methods, and scientific knowledge were identified from the experience gained in developing and executing prototype projects.

Additionally, the following objectives were pursued: i) to increase operational use of earth-observation data for policy decision making at national, regional, and global levels: ii) to provide validated products which can be used to derive reliable information concerning the forest component of the carbon budget for research and policy use; iii) to promote common data processing standards and interpretation methods, which are necessary for inter-comparison of regional studies; iv) to stimulate advances on multiple sensors, large volume datasets and information management and dissemination; v) to use data from multiple sensors, in combination with in-situ data, to produce validated prototype products which satisfy the identified users requirements; vi) to enhance the use of earth-observation products for forest management and scientific research concerning forest biophysical processes; vii) to provide the necessary tools for enhancing the actual use of current Spanish National Forest Inventories in order to support decisions at an operational level; and viii) to optimize ALS missions intending to reckon flight parameters for the determination of optimal and minimal configurations for the parameters retrieval at stand and tree levels.

During the Project, and in order to accomplish these objectives, different tasks have been carried out such as: i) analysis and definition of the requirements for simultaneous management of heterogeneous data; ii) establishment of LIDAR and digital camera data acquisition methodology; iii) definition of hyperspectral sensors characteristics; iv) establishment of land mobile platform data acquisition methodology; v) definition of characteristic parameters and specifications of the study ecosystems; vi) hyperspectral, LIDAR, NIR and in situ data acquisition; vii) post-process software development; viii) and analysis of data correlations.

3. Study areas

Three different forest ecosystems were considered in the present project, with different species, forest structure and climatic conditions, as well as very different management needs. The three study areas are located in Spain, as shown in Figure 1. A brief description of them is presented here.

The Pedroches region is located in Cordoba, in Southern Spain, and is covered by sparse vegetation dominated by *Quercus ilex* (dehesa forest). The main interest of the study was to lay the groundwork for the integration of different sensors, with different spatial, spectral and temporal resolution, in order to optimize the methodology for complex ecosystems assessment and monitoring**.**

The second study area, the Rodenal Region, is located in Guadalajara, in the Peninsula North-Central part of Spain. In July 2005, a forest fire affected around 12000 ha of *Pinus pinaster* and *Quercus pyrenaica* forests. The main interest in this area was to employ remotely sensed data to estimate fire severity levels and vegetation recovery, which provide very valuable information for forest managers to plan restoration works.

The third study area is Valsaín, a Scots pine (*Pinus sylvestris L.*) forest located in the province of Segovia, in Central-Northern Spain. The main interest of the study in this area was to determine the main parameters that could be estimated by LiDAR in order to provide inventory data which could help decision making of forest managers, not only for wood production purposes, but also for conservation measures, as the Valsaín forest is home for protected species, such as imperial eagle (*Aquila adalberti*), black vulture (*Aegypius monachus*) or the *Graellsia isabellae* butterfly.

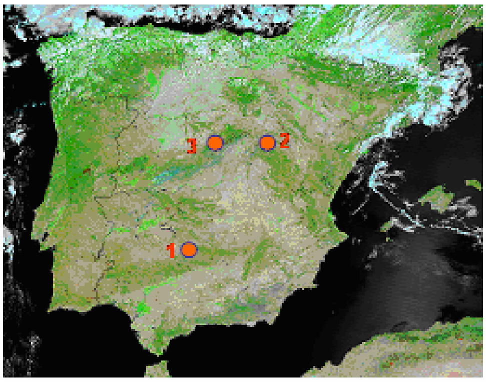

Figure 1: Study areas: (1) Pedroches, (2) Rodenal, (3) Valsaín (Terra-MODIS image acquired on 30/07/2005, downloaded from MODIS Rapid Response System)

4. Material and methods

For the three regions, flights were performed for the acquisition of combined LiDAR and photogrammetric data, using an ALS50_II Leyca SN073 LiDAR sensor and a DMC ZI SN020 digital camera simultaneously. The flying height was 1200 m above the ground, with a flight speed of 140 knots. Laser sensor parameters were set to a maximum scan frequency of 78 kHz and a laser field of view angle of 31º. For the photogrammetric survey, the following parameters were set: 12 cm ground sample distance, 60% forward overlap and 50% overlap between strips. In addition to the data obtained in the aforementioned flights, different kinds of field and satellite data were obtained and processed for the three study areas, as explained below.

The sensors involved were LiDAR, Landsat TM, Z/I DMC digital camera, a portable NIR spectrophotometer, and a GER 3700 spectroradiometer. To calibrate and validate the various sensors, six areas (of approximately 100 ha each) were selected, where on-field inventory data were collected: coverage of pasture, bushes and trees, existence of *Quercus ilex* regeneration, height, diameter at brest height, etc. The LiDAR and Z/I DMC camera survey was over 13000 ha wide.

In the Rodenal Region, a Landsat-TM satellite acquired 5 days after the fire (05/08/2005) was employed for the estimation of fire severity levels, while data from the LiDAR and photogrammetric flight were used for the monitoring of vegetation recovery. Field data consisting on a visual classification of fire severity levels were collected in July 2006. A second field survey was carried out in October 2007, which provided information about vegetation height and coverage, in order to estimate vegetation recovery in the area. The area surveyed by the LIDAR flight was about 4600 ha.

In Valsaín, a first survey allowed to complete some lacking information of forestry monitoring. Amongst other, different forestry parameters such as trunk and stem dimensions, tree heights, first branch heights, tree positioning, etc., were measured. The research has been carried out in a high-relief, dense forest compartment with tall trees in even aged stands. Some of the stands may be two-storied due to the presence of regeneration. Other accompanying vegetation are oaks (*Quercus pyrenaica*), common juniper (*Juniperus communis*), legume bushes such as Genista florida, ferns (*Pteridium aquilinum*), etc. Other surveys were focused on GPS georeferencing to support the LiDAR flights. The area surveyed by LIDAR was about 850 ha.

5. Results

5.1 Pedroches region (Cordoba, Southern Spain)

Spectral reflectance was measured on field intended to compile a specific spectral library as reference for elements identification (trees, pasture, soil) in remote sensing images. Vegetation coverage (especially tree coverage) is a fundamental parameter in forest management. In this work, an approach to vegetation coverage estimation has been planned by the combination of the different sensor advantages, at diverse spectral, temporal and spatial resolutions.

For detailed scales, an airborne digital camera Z/I DMC was used. DMC images (15 cm pixel size) were classified into a two-step procedure: Firstly, an unsupervised classification for sun lit soil discrimination has been applied to band 1 (in the blue region), which showed a better separability for the targeted classes (vegetation and shadowed soil -with low DN values- *vs*. sun lit soil, with higher DN values). Two classes were discriminated and a mask was applied to the image in order to separate the tree-crowns and their shadows. Then, a supervised classification was applied to the previously selected area. Three classes were considered: sun lit vegetation, shadowed vegetation and shadowed soil; a maximum likelihood algorithm was used for pixel classification. Tree coverage was obtained as a sum of both sun lit and shadowed tree crowns fractions in seven control plots, showing values from 6,6 up to 35,5% of tree coverage.

Using spectrometry field measurements on known-reflectance tarps (grey plastic-made, black plastic-made and white reference tarps -Spectralon, 99% diffuse reflectance standard- and a rocky surface), linear calibration equations have been derived for each DMC band, showing r^2 higher than 0,99 in all cases. These equations relate values measured by the digital camera to reflectance values at wavelength intervals corresponding to the four DMC spectral bands.

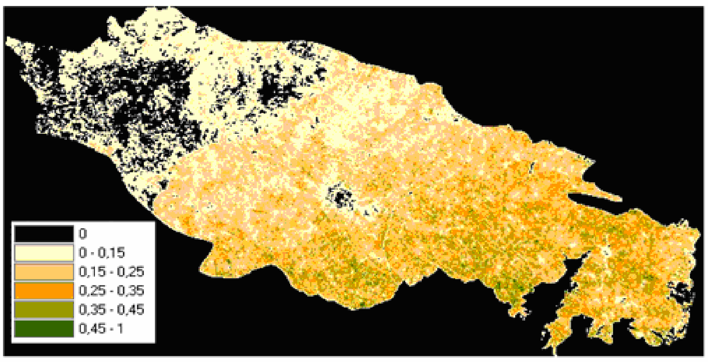

Figure 2: Tree coverage (values ranking from 0 to 1) per Landsat pixel in Pedroches area (Córdoba, Spain).

For a medium scale, Spectral mixture analysis was used to estimate subpixel vegetation coverage on a Landsat TM image (17th july, 2007). Given the forest coverage homogeneity in the study area, four components were considered: *Quercus ilex* trees (green vegetation in summer), dried pasture, soil and shadow. A linear mixture model was obtained using spectral field data (spectral libraries mentioned above). The model was validated using the previous DMC-based forest coverage estimate in seven plots, showing a correlation of $r^2 = 0{,}89$; also a certain tree coverage infraestimation was detected comparing Landsat model to DMC results (MBE = 2,8). Figure 2 shows *Quercus ilex* coverage in Pedroches area.

However, as historic DMC images were not available, temporal changes have been analyzed using Landsat imagery, comparing two linear mixture models from 1995 and 2007 images of the same area. In this period, tree coverage in Pedroches has shown to be stable in a 66,84% of the study area. Coverage variation has been lesser than 30% in all the cases; a coverage increase has been found in a 17,49% of the area, and a decrease in the 15,66%. These results fit with field data (defoliation, tree losses and establishment of new trees) periodically collected from 2000 to 2007 in six dehesa exploitations. RMS errors for both models are compiled in Table 1.

Table 1: RMS errors in linear mixture models

Model	RMS mean	RMS max	% of pixels with RMS max > 0,02
Landsat 1995	0,0036	0,0430	0,44 %
Landsat 2007	0,0064	0,2625	0,02 %

Besides, LiDAR data were used to obtain a vertical characterization of the different layers present in this region. The main interest in dehesa ecosystems is to assess the existence of *Quercus ilex* regeneration around the tree trunks, as the lack of regeneration is one of the main problems in this region. For that purpose, some different LiDAR digital models, such as Digital surface models (DSM), digital terrain models (DTM) and normalized digital surface model (*nDSM = DSM - DTM*) were reckoned using LiDAR ENVI Tools. Vegetation models allowed high detailed height distribution maps, as stems are clearly recognizable in the sparse vegetation cover. Within this situation, it is easy to make a comparison between LiDAR results and field measurements as individual trees are easily recognized. However, low regeneration trees or seedlings (under 50 cm) were not detected by LiDAR.

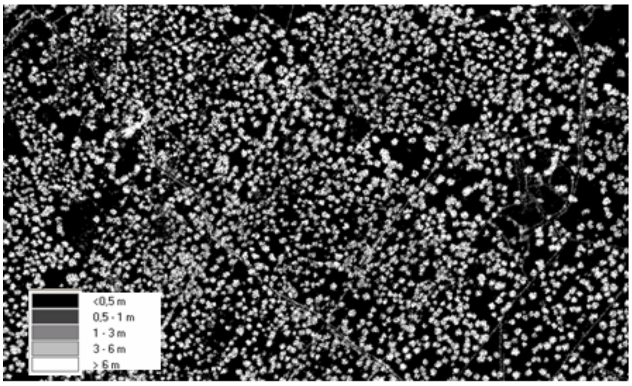

Figure 3: Distribution of maximum heights of vegetation in a dehesa area obtained from LiDAR data.

At a very high spatial resolution level, a portable NIR spectrophotometer was used on field for characterizing the spectral response from tree leaves, soil, shrubs and pasture. NIR sensors could be used either as a secondary measuring method, thus needing to be calibrated against a primary reference method, or it can be also used as a primary method using the spectral data alone to correlate with quality indicators (Williams, 2001; Shenk and Westerhaus 1995). The complexity of the spectroscopy signal and the great amount of generated data (most of it is redundant due to overlapping bands) are other factors affecting their use. However, the LINHE project dealt with the problem of generating both qualitative and quantitative chemometric models. In a qualitative approach, PLS2 discriminant analysis of pre-treated spectra (Standard Normal Variate and De-trending methods were applied) showed that NIR spectroscopy was able to correctly classify leaves coming from trees of different defoliation levels in an 86,5% of samples; and sun lit pasture *vs.* shadowed pasture in a 99% of cases.

On the other hand, quantitative models for estimating K and water content in *Q. ilex* leaves were calculated (n=100 leaves). This models are still preliminary and need to be improved using a higher quantity of samples. At the time these models become robust, they may be used to calibrate other sensors included in this project, or to describe dehesa ecosystems at a detailed level. For example, quantitative estimates of parameters from NIR datasets, using a manageable data volume for a complex project with lots of sensors, technologies and data from different sources.

5.2 Rodenal Region (Guadalajara, North-Central Spain)

One of the aims of the project in this area was to obtain a fire severity map based on satellite data that can be useful for post-fire forest management. The map was obtained by processing and classifying one post-fire Landsat-TM image, according to the following phases: i) first of all, a geometric correction was performed; ii) the Normalized Burnt Ratio (*NBR*):

$$NBR = (NIR - SWIR) + (NIR + SWIR)$$

was obtained so as to evaluate fire severity levels, as it combines the two Landsat bands with a most significant response to fire effects, band 4 (*NIR*) and band 7 (*SWIR*) (Key and Benson 1999); iii) the perimeter of the affected area was obtained, and a mask was processed containing only the burned area; iv) finally, a 3-class unsupervised classification was performed, which produced a map containing three levels of fire severity (high, moderate and low). More detailed information on this process can be found in Roldán et al. (2006). Field data on fire severity levels were used as “ground truth” for validation purposes. A global precision of 72,73% and a kappa index of 0,57 were obtained for the fire severity map. These results are considered acceptable, specially taking into account that only one post-fire image was used and that field data were only used for validation purposes, and not for training.

The second goal in this study area was to monitor vegetation recovery after the fire: to know whether there is vegetation growing in the area, and what is its height. For this purpose, LiDAR digital models were obtained: DSMs, DTMs and nDSMs provide information about vegetation cover and height. The combination of nDSMs and DTMs allowed to identify the different situations that can be found in the field: bare soil, surviving *Pinus* stands and *Quercus* sprouts. Bare soil areas were easily detected by using the DTM, while the nDSM clearly showed the surviving *Pinus* stands. On the contrary, many patches of very dense and/or very low *Quercus* sprouts were misclassified or unclassified. On the one hand, very dense vegetation makes it impossible for the laser beam to reach the soil, and those vegetation patches are therefore classified as terrain, which also produces inaccuracies in the estimation of the average height. On the other hand, very low vegetation (under 30 cm) is not even detected. These problems did not allow a proper assessment of vegetation recovery by means of LIDAR data. Riaño et al. (2007) and Streutker and Glenn (2006) suggest to use spectral information from aerial digital images acquired simultaneously to the LiDAR survey to solve the former problems. Unfortunately, this information did not prove useful in the present case, as the flight took place in November, when *Quercus* sprouts showed very little activity, and the acquired spectral information was therefore not valuable. Some improvement in the classification of *Quercus* sprouts was obtained by reducing the grid size when obtaining the nDSMs, but further work is necessary on this topic, so as to improve the mapping of *Quercus*.

5.3 Valsaín (Segovia, central Spain)

The LINHE tool for forest management was provided with Landsat ETM+-derived imagery of the study area. The Landsat ETM+ scene was atmospheric, radiometric and relief corrected. A cover map of Valsaín forest was generated by supervised classification of surface reflectivity, obtaining 8 cover classes: urban or residential, herbaceous, bush, woody perennials, deciduous, bare soil and water covers. The overall accuracy of the classification was close to 70%. Also, the surface moisture index was generated with PCI Geomatica 10.0 KOS Manager using the short wave infra-red (SWIR) band 5 reflectivity. Finally, the Normalised Difference Vegetation Index (NDVI) map of Valsaín forest was obtained from the red and NIR bands (3 and 4, respectively). All these products were provided to the LINHE tool server.

LiDAR height distribution derived from LIDAR digital models within wooded zones was related to distributions of heights, diameters, basal areas and volumes from field data obtained in the Valsaín pine wood. Therefore, a comparison was made between some parameters reckoned from in field measurements and those reckoned from LiDAR digital models. For this comparison, the next parameters were measured in field: diameter, tree height, height of the first living branch, stem width, tree position, basal area, trunk volume, stem height, area and volume, and vegetation density. A nDSM height average map was computed from LiDAR data. Figure 4 shows the Valsaín pine forest orthophoto image, superimposed with the crown model obtained from LIDAR data.

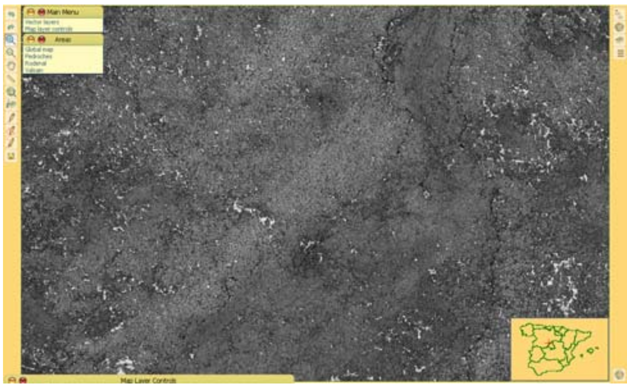

Figure 4: Orthophoto image of Valsaín pine forest, superimposed with vectorial LiDAR points

The first results of the comparison suggest coherence between LiDAR and field measurements, showing different average height in different testing zones. Height values of about 0 and 10 meters, which are expected in regeneration zones and zones with no homogeneous vegetation densities, have been observed. LiDAR height histograms have a great resemblance with distribution histogram variables from the forest inventory.

5.4 LINHE viewer

An important element of the LINHE tool is the LINHE prototype viewer, which allows a dynamic access to georeferenced data (raw and processed). The viewer is tailored with simultaneous access to the thematic results, querying properties, editing tools and printing of cartographic outputs.

The viewer is a very useful tool for data managing and cataloguing, meant to support data forest management, as it allows simultaneously visualizing a great amount of data (vector and raster layers) from the different sensors involved, with different spatial resolution and different formats. It is also a suitable tool for homogenization and standardization purposes, as the Inspire Directive (2007) has been applied. It can be considered as a useful complement to the more complex analysis tools used in remote sensing (commercial GIS programs). The viewer offers the possibility of i) performing some data analysis procedures such as vector layer queries, ii) visualizing the metadata of the information layers using ISO 19115 standard, iii) adding new vector layers, iv) measuring distances and areas, and v) generating maps in .pdf format for printing. The viewer's architecture is Open Source based, on geographical servers and client elements, and it has been developed upon a *free* and *open source software*, hence licensing is not required. Usage is intuitive and no prior GIS knowledge is required. A web access is the sole software installation requirement prior to working with the LINHE viewer. The viewer can extract and show on screen all the information contained in each point.

6. Discussion and future work

The different data types, methodologies and processing techniques employed and developed within the LINHE Project, and the variety of ecosystems considered, provide a wide range of relevant information for the analysis and management of forest ecosystems.

The LINHE tool fulfils the principal aim of the project, which is the generation and integration of different geospatial information layers for forest planning. LINHE Project was developed during two years, and unfortunately a large amount of time was employed in data acquisition. Although interesting results for data integration and forest management have been obtained, further analyses and deeper correlation studies are necessary in order to obtain more conclusive results. So far, ALS data have been use to reckon height digital models intended to estimate forest parameters such as mean height or position, but it is considered necessary to deepen into how LiDAR data can help to estimate other useful parameters for forest management and inventory. The analysis of LIDAR intensity responses is an interesting field which was not considered in the present project. Besides, further surveys with Terrestrial Laser Scanning (TLS) are planned as future work, from which very interesting results are expected.

In addition, new implementations for upcoming versions of the LINHE viewer are already planned, which are expected to include: i) raw data and thematic data downloading capabilities; ii) .shp file format export capabilities of new data records; iii) restricted user's access and iv) PDA data handling capabilities.

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