Planning and Acquisition of Control Data to Validate Forest Inventory and the Estimation of Fuel Variables Derived from LiDAR Data and High Resolution CIR Images

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Resumo. The estimation of forest and fuel variables by using LiDAR data and CIR high-resolution images is the main objective of the project PTDC/AGR-CFL/72380/2006 financed by the Portuguese foundation *Fundação para a Ciência e Tecnologia (FCT)*. To estimate those variables a novel software system needs to be developed and tested. To this end, control data are necessary. In this article it is addressed the planning and acquisition of traditional forest inventory data in pure eucalyptus strata as well as topographic data. The latter is acquired with the classical topographic methods by means of a total station and by using global positioning techniques with the help of high precision GPS receivers.

Key words: Forest inventory, fuel variables, LiDAR, CIR images

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Introduction

One of the indispensable conditions for a sustainable development is a detailed and up-to-date knowledge of the available natural resources. In the case of Portugal, an important natural resource is that of its forests. Crucial information for foresters and land-use planners concerns, in particular, tree species, tree position, stand density, dominant height and stand volume and biomass per hectare. In relation to forest fires – which have attained dramatic proportions in Portugal in the years 2003 to 2005 – the need for additional information on vegetation variables like density and height, as well as on terrain morphology must be stressed. Such information is fundamental for predicting the risk of ignition and fire dynamics.

Presently, the essence of forest mensuration is still in obtaining field information by sampling of trees inside plots and subsequent extrapolation to stands and large areas. Airborne laser scanning, by its nature, presents itself as a promising technique to obtain detailed 3D information about terrain and the mean tree crown and height, and thus volume and biomass, in a fast manner (SUÁREZ *et al.*, 2005; NAESSET *et al.*, 2004). Research related to airborne laser scanning for forest inventory has been active in the Nordic countries for about 15 years

(NAESSET *et al*., 2004). The research work used forest stands, with an area of 1 to 10 ha, as basic unit for forest management and planning. Thus, characteristics at the stand level are requested for strategic planning at the property level and for tactical and operational planning of silvicultural treatments and forest operations (HOLMGREN & JONSSON, 2004; NAESSET *et al*., 2004; GOBAKKEN & NAESSET, 2004).

For the management of productive forest stands it is needed to estimate the forest variables at stand level, with precision, such as dominant height, stand density, basal area and volume. HYYPPÄ *et al.* (2004) show that this is possible by using a high frequency laser scanning. From the laser data, individual trees may be extracted as well as some of its characteristics like height, localization and mean size of the crown. Laser scanning is also a valuable technique for the characterization of crown and surface fuel needed for the estimation of risk of fire and prevention (RIAÑO *et al*., 2003; CHUVIECO & MARTÍN, 1999). By penetrating the tree crown it reaches the shrubs and the terrain. Furthermore it also allows the estimation of variables related to the fire propagation, at terrain and crown level.

The estimation of the fuel variables, like biomass loads, plant geometry, and compactness, needs the knowledge of the horizontal and vertical structure of vegetation, which can be extracted from laser scanning or images (CHUVIECO & MARTÍN, 1999). For a correct estimation of the effect of the tree crown fuel, it is also needed to know the height of shrubs, which is used to estimate the probability of the vertical projection of fire (JOHNSON & KIYOKO, 2001; VÉLEZ, R., 2000). The presently used photogrammetric technique does not allow the estimation of the height of shrubs. Thus, it is important to explore the laser-scanning technique for this proposes.

The issues above mentioned related to forest inventory and estimation of fuel variables by new technologies are topics of research in the framework of a research project financed by the *Fundação para a Ciência e Tecnologia.* The research work proposes to develop a methodology for modelling the terrain relief and for estimating, in a fast and reliable manner, forest variables and its fuel (surface and tree crown). This methodology is then concretized in the form of a modular software system. Both, software and concepts have to be tested and validated by means of control data.

In this article it is addressed in detail the strategy and methodology developed to collect the control data, i.e., the field inventory and the topographic data.

Study Area and resources

Study Area

The study area was selected nearby the city of *Águeda*, in the district of *Aveiro*, situated in the Northern part of Portugal. The selected area measures 3 x 3 km^2 (Figure 1a) and, while dominated by eucalyptus plantations, also includes some pine stands and few built-up areas. The forest stands in the area comprise regular as well as irregular spacing plantations, both even and uneven-aged stands, and stands with as well as without extensive undergrowth. The topography of the study area varies from gentle to steep slopes, with altitudes varying from 30 to 160 m (Figure 1b).

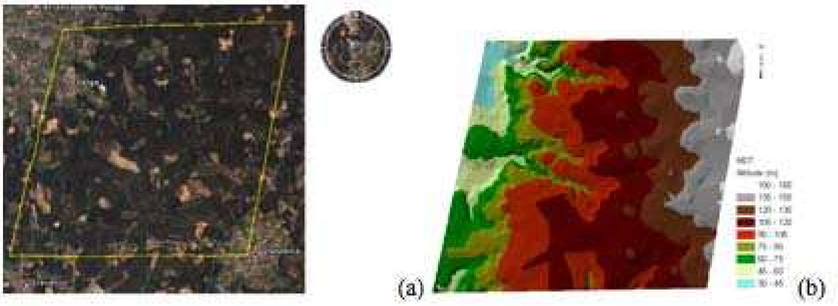

Figure 1 - (a) Study area delimited by a polygon; (b) Topography of the study area

Resources

The resources here addressed relate to equipment, materials, software, time and persons.
The equipment and materials used in the forest inventory were:

- PDA, GPS, a telescoping measuring rod, a calliper, a digital hypsometer with capacity to measure horizontal distances (Vertex), a photographic camera and batteries, a compass, normal ruler and a ruler of 50 cm, a 50 m measuring tape, an ordinary protractor, a drawing pen, ribbon marker and Edding markers, a pencil, a rubber, and a chart holder.

The equipment used to collect the topographic data was:

- Three high precision GPS TOPCON receivers, two TOPCON poles, two tripods NIKON, a NIKON total station, two poles NIKON, two NIKON prisms, and one NIKON tripod.

The software utilized was dedicated software to collect the field inventory data, TOPCON Tools, TOPCON Link, PCCDU, Trimble Geomatics Office, NIKON Exchange, Microsoft Access, and the ArcGIS.
The time needed to plan and acquire the control data was 7 months, involving, 6 persons. Whilst 2 months were needed for planning, one month was dedicated to collect the field inventory data and 5 months for the collection and processing of the topographic data and production of the database (3.2).

Main Input and Output

Main Input

The input needed for the planning phase of field inventory and topographic data collection are: aerial photography, orthophotos and topographic maps at scale 1:25.000 of the area, a forest land-cover map, a GPS plan together with the ephemerides and planning parameters (like maximum PDOP and minimum number of satellites (4.2)), and the approximate location of the GPS bases (4.2), marked on an orthophoto.
The output of this phase is the input for the next phase, the acquisition of both the field inventory and topographic data. It consists of the list of the plots to be inventoried as well as of the alternative plots with indication of their code number, the coordinates of the plot centres, the materialization on the terrain of the GPS bases (4.2) as well as their coordinates X

and Y, in the projection system WGS84-UTM, zone 29 and the Z coordinate (the Ellipsoidal height WGS84).

Main Output

The main output relates to:
- Forest Inventory.
- Coordinates, in the above referred system, of each tree in each plot.
- A Digital Terrain Model (DTM) of each plot.
- Coordinates, in the above referred system of the objects that will be used for quality control of the laser data.
- Error reports.
- A database.

Methodology

The methodology developed for the planning and acquisition of the forest inventory phase and for the planning and acquisition of the collection of topographic data phase will be addressed separately.

Planning and acquisition of the forest inventory

The forest inventory was performed on plots selected according to a grid with cells of 325 m x 325 m over the study area. As it was decided to test the developed system on eucalyptus, the preparation for the fieldwork concerned only pure eucalypt strata (480,928 ha). To select the plots to be inventoried, the grid was superimposed on the forest land-cover map (Figure 2) and 45 plots localized in the centre of the grid cells were selected as being forest (Figure 3). The forest land-cover map was produced by using an orthophoto of the area and photo interpretation techniques.

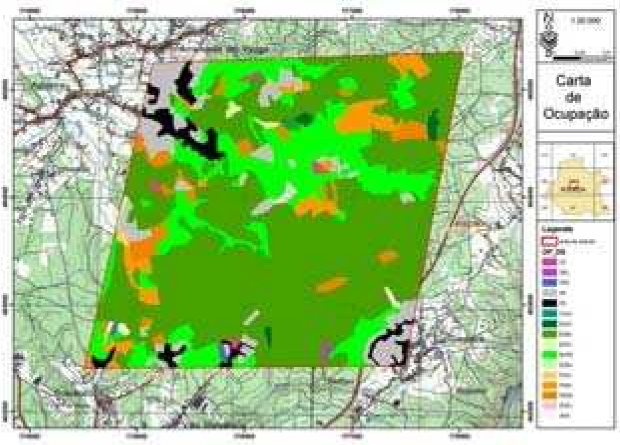

Figure 2 - Land-cover map of the study area

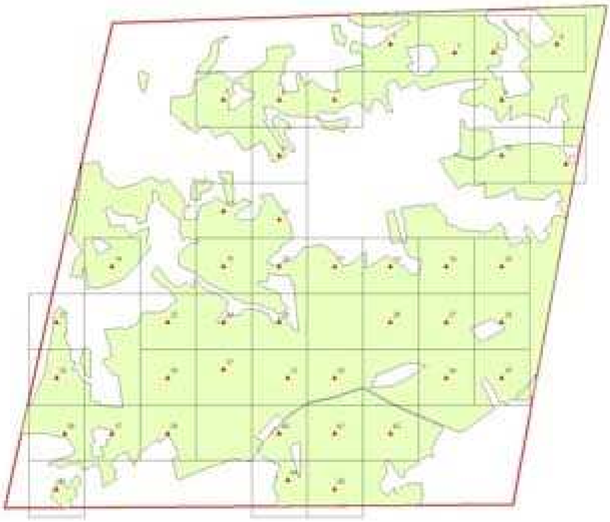

Figure 3 - The 45 selected plots

Within each grid cell an alternative plot to substitute the fist one if needed (like if the original plot would be inaccessible or wrongly classified) was determined. The alternative plot was localized 50 m to the right of the original plot. If this plot would fall outside the stratum area, it was moved 50 m to the right and then 50 m to the North. If it still would fall outside the stratum, it would be moved more 50 m in the directions North, Northeast, Southeast, South, Southwest, West and finally Northwest until it would fall inside the stratum.

The coordinates of the plot centres were determined by using the digital orthophoto and the software ArcGIS. They were stored in digital format in the WGS84 system.

For the acquisition phase, the referred coordinates were used with a GPS, in the navigation or position modes, to found and materialize the plots centres. In case the GPS cannot be used due to bad signal reception, traditional methods may be used as described in TOMÉ (2004).

The sampling plots are circular with 400 m^2 (radius of 11.28 m). Their delimitation has to be rigorous for a precise determination of the forest variables.

Within each plot a sub-plot of 200 m^2 is also considered for which were measured, in high stands or coppice stands after shoots selection, the total height and height to the base crown of all trees/shoots with a height equal to or greater than 2 m. Furthermore, at coppice stands was also measured the height of each stool.

In case a plot is localized at the edge of the stand, if its centre is outside of the stand, the plot is rejected. Otherwise, it is only considered the part of the vegetation that is located within the stand. The distance between the plot centre and the limit of the stand has to be measured. This will allow determining the percentage of the area of the plot inside the stand. Similar procedure is done when the plot has eucalyptus of different ages or structure. In this case, the distance between the plot centre and the "sub-stratum" limit has to be measured.

The classification of the forest stratum is validated in loci by observing around the plot centre the involving forest stand. A forest stand is a forested area with a minimum of 5000 m^2 and a mean width equal to or greater than 20 m.

Each plot is characterized according to:

- exposition;

- altitude;
- slope;
- physiographic situation;
- evidence of fire;
- erosion signs;
- grazing tracing;
- characterization of the vertical structure.

Furthermore, for each plot it was also registered/acquired:

- the inventory date;
- the walking and by car accessibility;
- the soil preparation;
- the age;
- the understory utilization;
- the management system: high forest, coppice or high plus coppice forest;
- the rotation;
- the spacing;
- thickness of litterfall in 4 sub-plots located in each of the 4 cardinal points 3 m apart from the centre of the plot;
- in high stands or coppice stands after shoots selection: diameter at base height (DBH) of all trees/shoots with total height equal to or greater than 2 m; the total height and the height-to-the-base of the crown of the 4 dominant trees/shoots; at coppice stands it was also measured the height of each stool;
- in coppice stands without shoot selection: total height and base crown heights of the higher and mean shoot at each stool; DBH of the mean shoot at each stool; all the live shoots were counted; the height of each stool;
- in young stands (with a mean height smaller than 1,30 m): the height of all trees;
- 4 photographs around the border of the each plot and other 4 around its centre. The order in which the photographs were acquired followed the cardinal points (N, E, S, W); 1 photograph was also acquired at the plot centre and towards up to get an impression of the vegetation density within the plot.

All the trees/shoots were characterized about their state (alive/dead) and health.

Planning and acquisition of the topographic data

Topographic data concern, per plot, the coordinates of each tree and a DTM. The DTM was decided to be represented by the coordinates of terrain points located aside trees, which give also the tree location, and by the coordinate of prominent terrain points, like those on breaklines (Figure 4). It was also decided to measure the edges of logging roads. These were also used to assess the quality of the delivered laser data, together with the delineation of rooftops and wells (Figure 5) and grids of approximately 1 m x 1 m grid points on flat surfaces (roads and fields) (Figure 6).

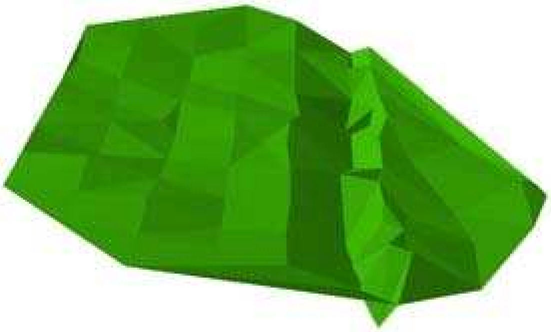

Figure 4 - The DTM of one of the plots

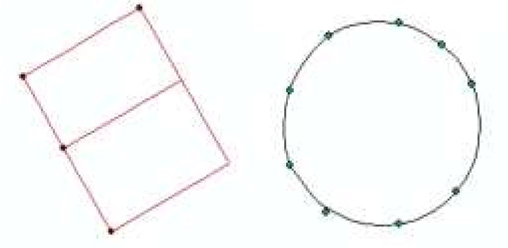

Figure 5 - Example of a roof of a house and of a well measured for the quality control of the laser data

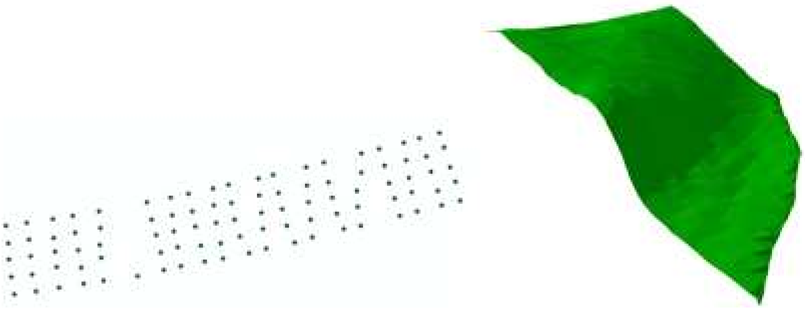

Figure 6 - DTM on flat surfaces (road and field) for the quality control of the laser data

The coordinate system in which the laser data were collected is the projection system UTM, zone 29, for X and Y coordinates, and the Ellipsoidal height WGS84 for the Z coordinate (from now on referred to as absolute coordinates). Because this is not a local system, the geographic information collected in the field had to be converted to that system by using the Global Positioning System (GPS). To this end, it was decided to attach to each plot two points, named GPS base, whose coordinates were measured with two, high precision, GPS receivers. These two points were placed as close as possible to the plot and as much as possible in an open space (figure 7). This criterion turned to be difficult to fulfil in the study area.

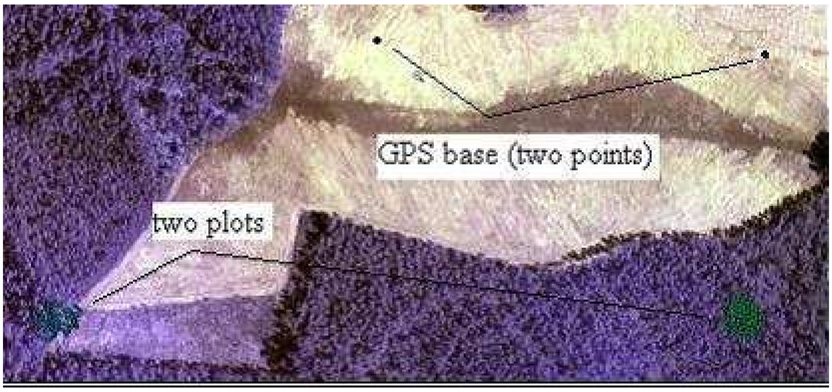

Figure 7 - A GPS base used for two plots; the green dots represent the measured locations of trees and of terrain points within the two plots

The method used to measure the coordinates of the two points that constitute the GPS base was the relative positioning by using a fixed receiver on a geodetic pillar with known coordinates on the above referred system. This method, in post-processing, is the most precise and may reach levels of precision in the order of the cm. The pillar was situated at a distance smaller than 10 km from the study area.

The GPS observations were collected according to a previous planning dictated by the following specifications: minimum time of observation of 60 minutes, depending on the point surroundings (normally it took 120 minutes), minimum number of 7 satellites and value of the Position Dilution of Precision (PDOP) less than 3. In total, the coordinates of 82 points, i.e., 41 GPS bases were measured. The number of GPS bases does not coincide with that of the plots because, firstly two of the plots were disregarded due to inaccessibility and secondly 2 GPS bases were assigned to two plots each.

The coordinates of each tree and the DTM were estimated by means of a topographic survey using the irradiation method and the absolute coordinates of the GPS bases. When these coordinates could not be directly transmitted to the topographic station from where the topographic measurements within the plot were measured, it was constructed a traverse network. To preserve the degree of precision of the order of cm the traverse had no more than four points.

Results and discussion

As a result of the forest inventory, the total height and the height of the base crown of 2272 trees/shoots were registered together with the general characterization of the 45 plots. These 45 plots represent 43 plots in pure eucalypt stratum, because two of the plots were inaccessible, plus 2 plots of pure maritime pine (*Pinus pinaster* Ait.) to extend the study also to this type of trees. This information was stored in a database, together with the topographic data.

The quality of the coordinates of the GPS bases was assessed by using the differences in X, Y and Z between of the coordinates of the two points of the GPS bases. These differences were estimated by using the coordinates computed in a local system and in the absolute system. The local coordinates are computed by means of topographic methods using a total station. It is assumed that the errors that originate from this source are negligible when compared to those originated by using GPS techniques. Furthermore, it is also assumed that there is no bias in the coordinates computed by using the GPS. In planimetry, the mean error and Root Mean Square Error (RMSE) are respectively 1,7 cm and 2,5 cm whilst in altimetry they have the values of 1,9 mm and 2,6 cm respectively.

Both the forest inventory and the topographic data and error reports are arranged in a database.

The most difficult task to accomplish has been, undoubtedly the planning of the locations of the GPS bases and the estimation of their coordinates. In fact, in dense forest environment, to try to estimate coordinates in the absolute system in the order of cm is quite difficult. This is due to the interferences of the forest in the GPS signal. To find open spaces close to the plots is a very hard task. If they are too far apart from the plots, their coordinates have to be transported by means of intermediate points degrading the quality. Such a high precision is needed so that the control data are reliable.

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