Automated Aerial Imagery Analysis System for Individual Tree Identification in Cork Oak Stands

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Abstract

An automated computer based system is proposed for individual tree identification in high-resolution remote sensed imagery. The system should be used for open forest cork oak stands (montados) and serve as a substitute for a human interpreter. The methods for distinguishing the background and the vegetation in open forest stands are presented, as well as the algorithm for individual tree identification. The algorithm is based on tree top identification and crown edge detection. Results obtained from the photo are compared with data measured in the field. Predictions are presented based on both data sets: field work and photos. The results appear to be usable for short time prediction of cork production. For longer period prognosis based on photos, the regeneration eliminated during the process is causing differences comparing to prognosis based on field data. This could be improved by regular remote sensing or partial field measurement.

Keywords: Tree detection, aerial photography, remote sensing, automatic system, pair-correlation function, cork oak, montado.

Introduction

Southern Portugal is a country with a dominant agrosilvopastoral ecosystem (montado), which is important for both soil protection and for maximizing land production. With pressure to increase land productivity, the need for good quality management tools is essential. Recently, a complete set of individual distance dependent tree models has been developed, able to handle sustainable management of the woody part of cork oak montados (Ribeiro et al., 2003). This complex model is presently available in a software environment, CORKFITS 2.1, and is used in a set of tasks for forest planning and management.

The individual tree models can easily reflect the system particularities like non-equal distribution of density, and mixed or uneven aged stand structure. Generally the use of individual models, especially distance-dependent, faces one principal difficulty — the availability of field data. The main goal of this work is

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to find a way how to fully or at least partly replace the human image interpreter with a computer, capable of making a set of decisions on its own, with a minimum of interpreter interventions during image processing and analysis.

Material and methods

Infrared photographs

Infrared remote sensed photography (NIR) was used in the present work. There are several reasons for using NIR photos:

- Infrared photography does not provide a way of seeing through fog, which consists of water droplets, but it can improve visibility through a certain kind of haze, where the light scattering is produced by much smaller particles. Accordingly, long-distance (aerial) photography can be improved. Infrared photography does not always result in an increase in the range of visibility, but it generally increases the contrast of distant objects and thus the amount of detail that can be seen.
- NIR reflectance decreases as a result of a change in leaf orientation, from predominantly horizontal to predominantly vertical, at a certain stage in the growth cycle, and it also decreases with the loss of leaf chlorophyll due to different reasons such as tree illness and damage. According to this NIR reflectance is without doubt species specific due to its dependence on these factors (Gitelson, 2002)

Photos taken in September 1995 were used in this work. The focus length was 154, camera type Zeiss RMK Top 15/23, and the scale of the photo was 1:40 000. The photos were scanned with a pixel resolution of approximately 40 x 40 cm.

The field data were collected in spring 1996.

Algorithm description

Detection of vegetation from background – region of interest

In open forest stands (montados, dehesas) a method for individual tree identification requires an additional step when compared to similar work in northern, denser forest stands. This extra step is used to distinguish photo parts representing vegetation and background. Commonly this is used with a term ROI – Region of Interest. ROI is part of the image, which is important for analysis. Generally a digital image consists of several areas, for example: vegetation – background, roots – soil, etc. These parts can be further divided into several other parts that are more or less interesting. Parts of the image that are essential for analysis are usually marked with the term ROI. In this work, ROI is the vegetation area in the image, which consists of vegetation and background (soil) area.

Several methods to handle such a task were previously developed, mostly in agriculture. A number of methods have been tested and a new B-square index was chosen to be used. B-square index is defined as a level of G channel in RGB cube, after transformation of all colors inside the cube to its walls with direction corresponding to the lightness. Whole process is described in details in Surovy et al. (2004). B-square index was performing equally with all other filters tested in terms of accuracy. Difference was mostly in the underestimation, where B-square index was the best This usually appears as white spots in "black" vegetation. This kind of error can be very easily removed by appropriate smoothing. Smoothing the "overestimated" image (the case with opposite error) can cause deletion of small trees.

After applying the index, the image is transformed from a full colour image into a simplified one. Subsequently a distinguishing procedure must be applied, termed "thresholding". Thresholding is a type of image segmentation process where an image is divided into parts (segments) using the image histogram. A image histogram is a chart displaying quantities of pixels with certain grey level over these levels.

A histogram of images with only vegetation and background is typically bimodal, where one peak corresponds to the background and the other to the vegetation. But the local minimum between the peaks, which is usually used as a distinguishing threshold, is in some cases not easy to define automatically. Sometimes, mostly on images with very high or very low vegetation fraction of the image it is difficult to define the peaks. But generally the histogram can be split into three parts, where two parts of them are vegetation and background levels of grey, respectively, and the third one is the distinguishing or edge level of grey. The term "middle valley" was established for this part of the histogram, and it is always placed between the other two (Perez et al., 2000).

In this work two possibilities were tested. A fully automatic system, where the threshold and all other procedures were done automatically, and also a semi-automatic, where the frequency histogram in each case was displayed and the user was asked to agree with an automatically defined threshold.

Gaussian smoothing

High resolution imagery usually has problems with too detailed crown "scans", where small holes in the crown or a longer branch without leaves can force the automatic system (looking for the local grey maxima) to distinguish more trees than there really are. Coarser levels of scales, on the other hand, can cause a tree crown to merge together with its neighbors or can lead to very small crowns disappearing. Sophisticated Gaussian smoothing is thus used to simplify finer scale images and remove noise Generally there are more methods. Simpler and therefore easier and faster to compute is the average smoothing where the value of center pixels is calculated as an averageof kernel, which size has to be defined. Average smoothing is generally not sensitive to the extremes, which can represent crown edges, and therefore using a too big kernel can cause a misplacement of the edges or other important parts. Gaussian smoothing is more sensitive to these extremes because of its kernel shape. The idea of this method is to approach the process in an interpreter's way of vision and to group the details of one crown to one "blob", which represents a crown with its grey level maxima.

Primary crown sketches delineation

There are three basic methods used in remote sensing for delineating the tree crowns (Brandtberg, 1999). The first identifies the local intensity maxima or minima respectively, because this pixel or group of pixels usually corresponds to the tree top (peak). Often this peak can be shifted towards the sun a little bit because it corresponds to the peak's most illuminated part. In a very dense group of trees there might be no direct local density maxima or just one for the whole group.

A second approach for delineation of the single tree crowns is contour-based or valley-based. Contour is usually defined as a delimiter between object (crown) and the background, whereas another term "valley" is used to define the delimiter between two different crowns (objects). The first approach of this technique was developed in Canada and is called the Crown Following Approach (Gougeon, 1995).

The third technique, where the task is to find tree crowns but also other image objects, is called template matching. It is the most computationally demanding way, if the authentic idea with many different templates is used. Each template represents a possible geometric crown shape. The first vision of this method capable of recognizing the individual tree crowns was developed in the 1990's in British Columbia, Canada (Pollock, 1996, cited in Brandtberg, 1999).

The present work is a combination of the first two above-mentioned techniques. First the system begins to look for the darkest (when using the B-square index) pixel in the whole image. This pixel is considered as an initial point for the following steps, where in all possible directions there is a search for a valley or a contour of the crown. The contour is found when the next pixel in direction being observed is marked as background. The valley is found when the next pixel gray level is significantly higher (difference is greater then one) than the present pixel. This should mean that the reflected lightness is increasing because of another crown segment. The information about crown segment is stored and analyzed. Each angle length (crown ax) measured is compared with lengths measured for two units backwards and forwards. If the processed length is significantly different - if it is an outlier among the other four lengths - its size is set to the average of these four. This is done because some outliers can appear due to the rounding and also sometimes there is no valley in certain directions, or the system can go through the same grey level of the other tree. After this process of "edge smoothing" all pixels belonging to the crown segment, including the edge pixels, are marked and they are excluded from subsequent analysis.

This procedure continues with the darkest point from the rest of the image and repeats itself until there no pixel, defined as vegetation, is left.

Sketches filtering

The amount of primary sketches found with the automatic system compared to ground truth is usually much higher. This is caused by several reasons. Often the mentioned smoothing is not successful enough and results in two local maximums close to each other. This causes the delineation of two peaks where the darker one is considered as a tree and therefore its crown shape can close the other false peak inside the crown. If the other peak is sufficiently big, this problem is not resolved with the "edge smoothing" process. The false peak is then considered as a tree, but its shape and position is not normal.

Therefore all structures with abnormal shapes, e.g. one part several times bigger then the rest and rounded with another sketch, are eliminated, as well as all tree sketches smaller then 40 cm of perimeter. In this way, also the regeneration trees disappear, but the amount of sketches misclassified as trees because of the incorrect or incomplete cutting is much higher then the lost regeneration trees.

Tree characteristic generating process

The automated system is able to find only information about the tree stored in the image. That is represented by the tree position and the tree crown dimension and shape. These two variables are an outcome from the image analysis process. For simulation runs and study, some other tree characteristics must necessarily be generated. As an input to the software it is important that each tree has its identifying number. The X and Y position must be recalculated to be oriented to the center with coordinates (0, 0). The dependency between crown area and stem area in breast height (1.3 m) is known. In order to estimate stem diameter with crown area measured on the photograph, the equation of back-calculation is used. A similar process is used to estimate the tree and crown heights. The last variable needed - stem height - is defined randomly. All variables are stored in text file, which can be processed with the growth simulator CORKFITS 2.1.

Results

Several control plots were installed and measured in the field. The centre of the plot was installed and then distance and angle with respect to north was measured for each tree in a radius of 40 meters. These values were afterwards recalculated to x and y coordinates relative to the center with coordinates (0, 0). The following was measured for each tree: circumference in breast height (1.3 m), tree height, crown height, biggest crown ax length and angle to north, lengths of three more axis every 90 degrees in clockwise direction.

The position of the center of each plot was defined in the photo using a Global Positioning System (GPS). Regarding the photo scale and pixel resolution, the area corresponding to the area of the ground truth plot was delineated in the photo. This area was processed with the automatic system. Only the inner part of each photo (nadir area) was used for this process. Apart from a simple comparison of the number of trees found with the automatic system to the amount measured in the field, another characteristic was evaluated - the stand structure.

The stand structure is the most important part of the field measurement for individual distance dependent tree models. The distances between trees, regarding the individual tree model structure, provide information about the competition between them. As previously mentioned, sometimes the crown peak obtained from the photo can be moved towards the sun. A simple comparison of the positions, measured on the ground and delineated from photos, would produce an error. But if both trees are moved in the same direction, the most important information – the distance – will remain correct. Therefore a method of evaluating the stand structure was used. The pair–correlation function (Stoyan and Stoyan, 1992, cited in Biber 1998) regards the horizontal distribution of the trees in relation to a random distribution without considering their dimensions. Pair correlation functions enable one to decide, whether pairs of the trees at a certain horizontal distance occur more or less frequently than we would expect for a random distribution.

The data obtained from the automatic system were compared with ground truth data, which were previously filtered with the same filter as the primary sketches extracted from photos. This filtering procedure eliminates trees covered by other trees, as well very small ones, which are invisible on the photo. This step is important to avoid mistakes because of these trees.

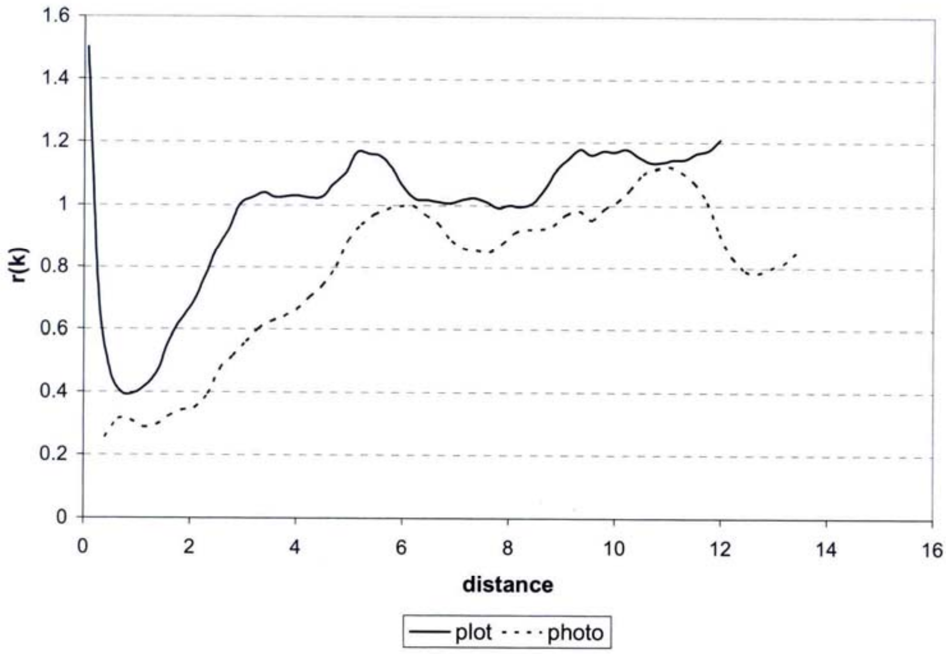

Fig. 1: Pair correlation function chart, x-distances, y represents values g(r) of probability of certain distance between two trees. Dotted line is plot obtained from the photo; solid line is the real plot. This case shows an example where stand's structure was not well delineated from the photo, structure delineated from photo shows lower density in smaller distances then in the reality.

Results

The number of trees measured with the fully automatic system had an average error of 37.6 ± 22.5% while the average tree amount error extracted from the semi-automatic system was 19.1 ± 20.8 %. Structure comparison results varied from very good (Fig. 2) to average (Fig. 1). The values of function g(r) in Fig. 2 are higher in distances between 10 to 17 meters. Lower values of g(r) in smaller distances and shape of the curve means that the stand is more regular when there is no cluster structure and the trees are spread regularly and not grouped together. High probability (high level of g(k)) occurring in relatively big distances (17 m) can be explained as the information about less dense stands. In contrast, in Figure 1 it can be seen that the real plot curve has its local maximum in very small distances. It means that there is a high probability that the trees are more close to each other. The presence of lower probabilities in higher distances means that this stand structure is a bit clustered.

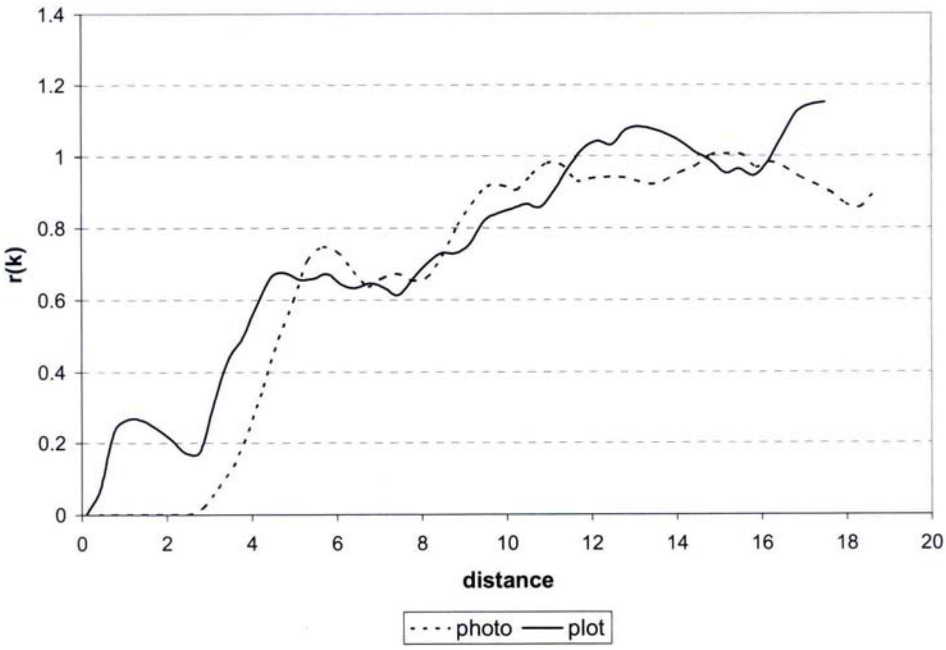

Fig. 2: Pair correlation function chart, x-distances, y represents values g(r) of probability of certain distance between two trees. Dotted line is plot obtained from the photo; solid line is the real plot. This case is an example of a very good result, where a less dense structure was successfully delineated in the photo.

In Figure 2 it can be seen that the real plot curve and the photo curve are quite similar and they do not show a significant difference. In Figure 1 the high probability in small distances showed in the real plot curve does not occur in curve obtained from photo. This means that the group of trees close to each other was merged by the algorithm.

Figure 3 shows the simulation run for crown cover. Two different curves of crown cover development are shown; one is based on data obtained from the plot, and the second one is based on data measured with the system in the photo. As can be seen, the curve of the photo data decreases more quickly, which is caused by the possible lack of regeneration existing in the real plot.

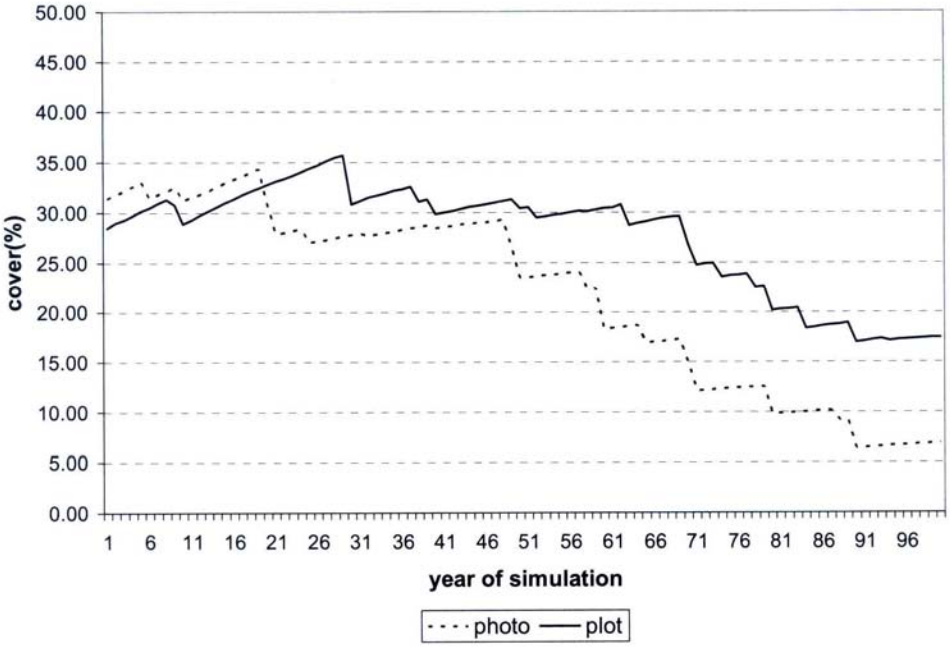

Fig. 3: Example of simulation of the crown cover processed with data obtained from the photo and data obtained from the plot.

Conclusions and discussion

The presented algorithm is still being developed. The results obtained so far appear to be promising and the method could serve as a good alternative data source for tree growth simulator CORKFITS 2.1 and other purposes.

The automatic thresholding step causes one of the most significant error reasons. Structure obtained from the photo employing the automatic system can be different from the real one because of several reasons. As the tree amount is not extracted exactly, some trees in certain distances are lost, or on the other hand bigger trees can be divided into smaller ones. This increases the probability of small distances, as shown in Figure 1. A very promising method could also be the one described in Dralle and Rudemo (1997), where the number of trees is known before the automatic system starts, so one of the uncertain variables coming to the structure estimation is eliminated. This information could be retrieved from national forest inventories or by installing smaller plots.

It is not expectable that this system will be able to fully replace field measurement, because there are some technical limits in the image remote sensing process and much information is simply not saved in the image, e.g. small trees under other larger trees or too small trees. However, this method could be definitely quicker and more reliable, if done correctly, than the method employing a human interpreter. The biggest advantage of the method is the cost level, which is minimal. Loss of small trees (up to five years) in short run simulations is not an important problem, because for the estimation of production or crown cover the error introduced is small. If remote sensing is carried out regularly, every 5 or 10 years, a new input database can be generated for the simulation.

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