Biometry: the characterisation of chestnut-tree leaves using computer vision

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Abstract – **The Department of Biology of the University of Trás-os-Montes e Alto Douro analyses every year a large number of chestnut-tree leaves, in order to measure their biometric characteristics, namely the leaf area, dimensions of the enclosing rectangle, number of teeth and secondary veins. Because for a human operator this is a time consuming and error prone task, a computer vision system has been set up to improve the process. The task of measuring the leaf presents no major problems, while counting the number of teeth and secondary veins has proved to be complex at the resolutions used.**

This paper describes the state of the project, going into some detail on the algorithms. A complete system has been assembled, based on an PC connected to an imaging system. A windows-based application has been developed, which integrates the control of the operations to grab, store and analyse images of different varieties of chestnut-tree leaves in an organised way. Because the accuracy of the computer vision algorithms used is not sufficient for the system to be completely autonomous, a semi-automatic solution has been adopted. The operator validates or corrects the results of the automatic analysis. This solution leads to a significant improvement in the performance of the human operator, both in terms of speed and quality of the results.

I. INTRODUCTION

The Department of Biology of the University of Trás-os-Montes e Alto Douro analyses every year a large number of chestnut-tree leaves, in order to measure the following biometric characteristics (see Fig. 1):

- dimensions of the enclosing rectangle (1 and 2);
- length of the petiole (3);
- area;
- number of teeth in each side of the primary vein (e.g. 4);
- number of secondary veins in each side of the primary vein (e.g. 5).

Because for a human operator this is a time consuming and error prone task, a computer vision system has been set up to improve the process. The system uses a digital image of the leaf illuminated from bellow. Different illumination solutions, with several different light sources have been tried.

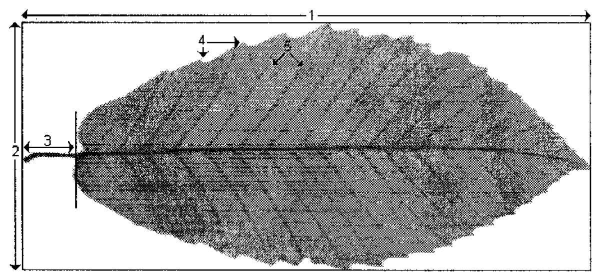

Fig. 1. An example of an acquired image, with the indication of relevant biometric characteristics.

The tasks of measuring the dimensions of the enclosing rectangle, the length of the petiole and the leaf's area present no major problems.

Counting the number of teeth and secondary veins has proved to be complex due to the variability of the images. It is difficult to find algorithms which are generic enough to perform well in most cases and, at the same time, cope with some less frequent situations. The developed algorithms perform well, but the accuracy attained is not adequate for an autonomous system. Perhaps using higher digital resolutions the problem can be alleviated, but this is not possible with the equipment used at the moment.

The adopted solution was to build a semi-automatic system, where a human operator validates or corrects the results of the computer vision algorithms. Typically for each leaf the human operator has to correct two or three mistakes of the automatic system, which leads to a significant improvement in his performance, both in terms of speed and quality of the results.

The paper is organised as follows. Next section describes the set-up for image acquisition and digitalisation. Section III is dedicated to the task of measuring the dimensions of the enclosing rectangle, the length of the petiole and the area of the leaf. Sections IV and V focus on the algorithms used to count respectively the number of teeth and the number of secondary veins. The application interface is described in section VI. Finally, section VII presents the results and gives some directions for future work.

II. IMAGE ACQUISITION AND DIGITALISATION

The quality of the digitised images plays an important role in the performance of the system. A set of experiments has been conducted in order to define stable acquisition conditions that fulfil a set of minimum requirements. These requirements are related with the differences in grey level between areas in the leaf and in the background, and between the areas in the leaf that represent veins and the others.

The best results were achieved with the leaf illuminated from bellow, producing a see-through effect, useful to enhance the secondary veins. Various light sources and diffusion materials were tested and a violet incandescent lamp has been selected. A white paper has been used to diffuse the light. To reduce the lack of uniformity of the resulting illumination, the light source has a reflective surface around the lamp. Since influence from outside illumination is undesired, the system comprises a small dark chamber for image grabbing.

For digitalisation a *Data Translation® Vision-EZ*™ DT55 board is used. The images are 768x512 pixels. The Bitmap format has been selected to store the images on disk.

III. MEASURING THE LEAF

Besides counting the number of teeth and secondary veins on each side of the leaf, some auxiliary measures are also required, namely the leaf's area (in square-centimetres), the dimensions of the enclosing rectangle and the length of the petiole (both in millimetres). The implemented techniques are described in the present section.

The first step to determine the leaf's area is to eliminate the petiole from the image, since it must not be considered [1]. After the elimination of the petiole, the number of black pixels along each column is counted, within the limits of the leaf's contour.

The dimensions of the enclosing rectangle are determined simply by subtracting the x co-ordinates of the right-most and left-most points of the leaf's contour (which gives the total length of the leaf) and the y co-ordinates of the upper and lower points of the leaf's contour (which gives the maximum width of the leaf).

In order to measure the length of the petiole, the following procedure is used (see Fig. 2). We begin by counting the number of pixels belonging to the leaf in a column, beginning in a predefined position (B) and advancing to the left (leaves are always in the same position). When there is a sudden change in the width of the leaf (C), a small movement to the right is tried in order to precisely locate the end of the petiole (D).

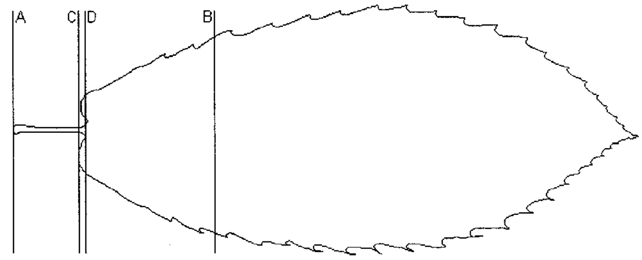

Fig. 2 – Measuring the petiole.

The position of the end of the petiole is important as a starting point for the splitting technique for teeth identification.

The measures are obtained in pixels and converted to metric units. In order to define the conversion factors (for x and y), a special procedure may be used at start-up.

IV. COUNTING THE NUMBER OF TEETH

Two methods have been tried in order to identify the teeth of the leaf, both based on the analysis of the contour (Fig. 3):

- a method based in a contour splitting technique;
- a method based on the analysis of the chain code.

In order to extract the contour, the image is first binarised. A contour following algorithm is used to extract the 8 directions Freeman code.

The first method, already used by Filipe et al [2], is based in a contour splitting algorithm as described by Tavares [3]. The leaf has been divided in three different zones, in order to use different parameters and so more accurately approximate the contour. A list of critical points is obtained. Some of these points (most of them points of high curvature) represent teeth, while others do not and should be ignored.

The elimination procedure is based on the heuristic that a critical point representing a tooth should be in a angle of less that 155° and the bisectrix of the angle should point to the interior of the leaf.

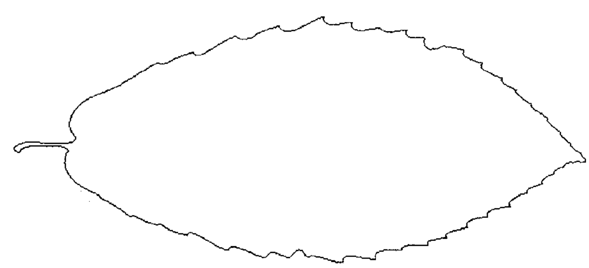

Fig. 3 – An example of a leaf's contour.

The second method is based on the analysis of the chain code. It uses the assumption that a tooth represents a sudden change in the chain code direction (Fig. 4). The analysis of the direction change is made between an i^{th} point and a $(i+j)^{th}$ point, with j=2,3,...,7.

As none of the techniques has proved very precise on its own, a combination of both has been used. The splitting technique is used as the main technique. When the distance between to consecutive teeth is considered to long for the area of the leaf being analysed, the chain code method is used to look for teeth that may have been ignored. In order to reduce the number of false matches, the number of iteration is reduced to two (j=2,3).

V. COUNTING THE NUMBER OF SECONDARY VEINS

At first a Hough-based method for line detection has been tried [4], [5]. The method takes advantage of the fact that most secondary veins have approximately the same inclination to reduce the search space. Several variants have been tried with good results [2]. When it has been decided that an interactive solution would be adopted, this method has been abandoned, because the information about the location of the veins is very imprecise.

A second solution has been developed. The image is filtered by a local threshold operation in order to segment the secondary veins. The result is illustrated in Fig.5.

The secondary veins are detected in this image by looking for dark regions in horizontal cross sections slightly above and below the primary vein. When a dark area is found, it is tested by trying to reach the vicinity of the leaf's contour following a path of continuous black pixels.

If no continuous path exists to the leaf's contour another test is used to prevent missing secondary veins which were broken in the threshold operation. This test tries to approximate the secondary vein by a straight line, with an inclination angle that varies from 30° to 100°, as ilustrated in Fig. 6. The black and white pixels intersected by the line are counted and a black/white ratio of 1.2 is used as a threshold value.

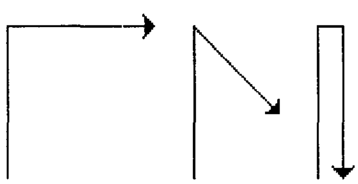

Fig. 4 – Sudden changes in the direction of the chain code (referred to an arbitrary starting direction).

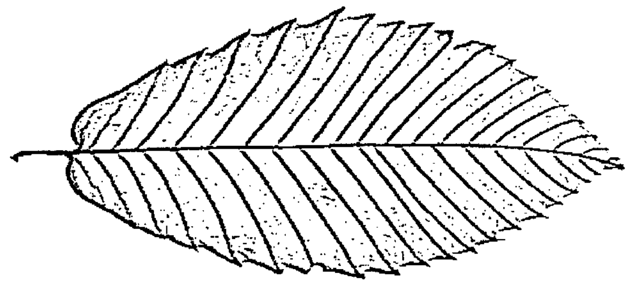

Fig. 5 – Thresholded image used in the detection of secondary veins.

VI. THE INTERFACE

Although some improvements are possible with the current acquisition system, it soon became clear that implementing a full automatic system at this point is not viable. The adopted solution has been to integrate the algorithms which had been developed with a user interface, in order to improve the productivity of a human operator. The operator validates or corrects the results of the automatic analysis.

The aspect of the interface is shown in Fig. 7. Simple menus and buttons make it very easy for an operator to become acquainted with the system. The system has been implemented in *Borland® ObjectWindows™ for C++ 4.02.*

VII. RESULTS AND CONCLUSIONS

The performance of the algorithms described in the previous sections has been tested in a database of leaves, previously classified with the help of experts in the field. The database contains 60 images of different varieties of chestnut tree leaves (2013 teeth and 2291 secondary veins). The results are shown in Tables I and II.

The work that has been developed shows that it is viable to produce a full working system with the desired functionality. The prototype version has as the weakest point the image acquisition system, which is hand-made and does not provide the required quality standard for the images (resolution is poor and the illumination is not uniformly distributed).

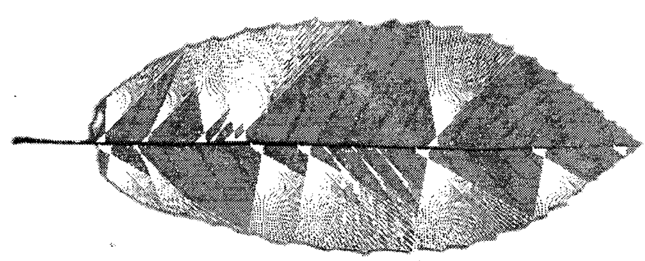

Fig. 6 – Illustration of the position of the straight lines used in the detection of secondary veins.

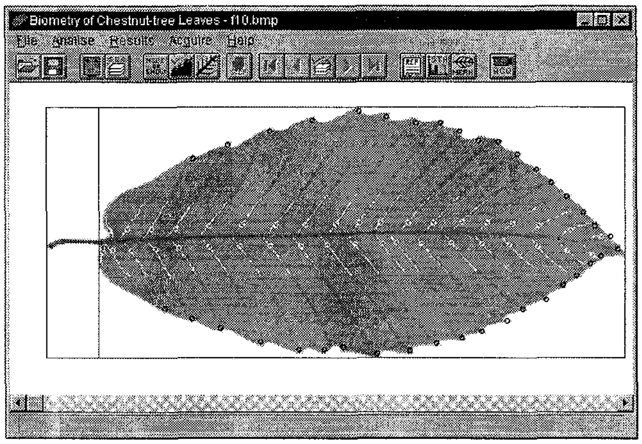

Fig. 7 – User interface showing automatically identified teeth and veins.

Some points may be noted:

- the dimensions of the enclosing rectangle, the length of the petiole and the area of the leaf are well measured; the results conform to the ones obtained manually;
- while counting the number of teeth and secondary veins in each side of the primary vein, even with the image quality presently available, the prototype represents a highly useful tool.

Future work should concentrate on improving the image acquisition system. As pointed before, image resolution should be higher and the illumination should be better distributed.

From the algorithmic point of view, it is believed that a neural network based approach should help in better identifying both teeth and secondary veins. In fact, preliminary results of a neural network based solution for the identification of teeth, using the chain code, show that this technique may be viable.

TABLE I
TEST RESULTS (TEETH IDENTIFICATION)

Teeth	*Splitting method*	*Chain-code method* (6 iterations)	*Splitting + Chain-code* (2 iterations)
correctly identified (in percentage)	1794 (89.1%)	1854 (92.1%)	1860 (92.4%)
ignored (in percentage)	219 (10.9%)	159 (7.9%)	153 (7.6%)
false matches (in percentage)	18 (0.9%)	88 (4.4%)	44 (2.2%)
total error	11.8%	12.3%	9.8%

TABLE II
TEST RESULTS (SECONDARY VEINS IDENTIFICATION)

Secondary veins	
correctly identified (in percentage)	2081 (90.8%)
ignored (in percentage)	210 (9.2%)
false matches (in percentage)	141 (6.2%)
total error	15.4%

VIII. ACKNOWLEDGEMENTS

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