Robust vein extraction on plant leaf images

Norbert Kirchgeßner[1] Hanno Scharr[1,2] Uli Schurr[2]

[1] Interdisciplinary Center for Scientific Computing, Ruprecht Karls University, 69120 Heidelberg, Germany
Norbert.Kirchgessner@iwr.uni-heidelberg.de [2] Institute for Chemistry and Dynamics of the Geosphere III: Phytosphere, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

ABSTRACT

In this paper an algorithm for robust extraction of leaf veins on plant leaf images is presented and tested on several images. It accomplishes a structure tracking by taking spatial information into account. The final result of the algorithm is a representation of the leaf veins as b-splines which contains the hierarchical information of the vein system. This allows to sample previously estimated affine growth rates along and normal to the plant veins. Thus they can be represented in physiological coordinates. This is vital botanists to compare the results of several leaves and species.

KEY WORDS

2D structure tracking , line extraction, b-splines

1 Introduction

The analysis of plant leaf growth with the structure tensor (ST) has recently been reported [10, 11, 12]. The ST method yields growth rates of plant leaves in image coordinates to a high precision. A botanical interpretation needs the data to be in a form that allows comparisons between different leaves. Therefore the results of the growth analysis have to be transformed into a coordinate system affixed to the leaf. The obvious axes of this coordinate system are the leaf veins. We developed a robust extraction of leaf veins on plant leaf images as a list of b-splines. This can be used for a coordinate transformation of growth maps and spectroscopic measurements into leaf coordinates (sect. 4).

Another question of botanical interest is, whether growth takes place similarly along and across main and side veins. This question can be answered by analyzing the growth distribution along the veins. We can investigate this by extraction of the vein system and its continuous representation by b-splines. This allows us to resample already estimated growth rates across and along the veins. This technique can be used for any kind of areal measurement on the leaf.

Plant leaves are well structured objects consisting of line-like veins and areas in between (see fig. 1). The leaf vein system is a hierarchical entity with a main vein and side veins of possibly several orders. The purpose of this work is the development of an interactive tool which helps botanists to extract the vein system with its hierarchical properties with as little user interaction as possible.

The first step in the vein extraction process is a correction of illumination inhomogenities. Secondly a tracking algorithm, which samples lines along several directions is used [3]. In comparison to the previously used algorithm [6] the new one utilizes integrated information from an area making it much more robust. As we put focus on robustness, the algorithm does not stop necessarily at the end of veins. From botanical studies we know where the side veins, assigned to a certain main vein, have to end. We use this knowledge as a search constraint.

The result of this step is a point list for each vein. These points are used as fulcrums for the conversion of the found lines into b-splines.

With the b-splines we can sample the area around the veins and compute growth maps of this region. This is important for the comparison of growth maps measured on different leaves.

Paper organization. We start with a description of the presented algorithm (sect. 2). Then we show some sample experiments (sect. 3) and finally we summarize and give a short outlook (sect. 4)

Related work. The analysis of plant leaf growth has been of botanical interest for a long time [9]. Through the structure tensor technique (ST) [5, 2], spatial and temporal resolved growth measurements have been estimated for the first time [10, 11, 12]. For an interpretation, growth measurements need to be transformed into physiological coordinates, this has already been achieved for plant roots [7]. Therefore we need to extract the veins on plant leaves which has already been achieved by a previously proposed technique [6, 8]. This previous technique does not work properly for side veins. As the veins are bended lines, the hough transform [4] is not suitable for their detection. Even a sequential hough transform [13] does not seem to be practical because the veins would consist of very many pieces. We use a successive detection method which has been proposed in [3] for 3D microscopic data. It was extended for the extraction of leaf veins.

2 Vein search

In this section we describe the detection of the leaf veins in detail. First the image is preprocessed and the tracking parameters are initialized (see sec.2.1). Then we specify the general search principle. Next the search for the main veins and their conversion into b-splines S_m is described. Subsequently we describe the automatic initialization of the parameters for the side veins and their search. The result is a list of b-splines of main veins S_m and a list of b-splines of side veins S_s.

Figure 1: Original image of a plant leaf of ricinus comunis.

2.1 Preprocessing and initialization

In order to compensate inhomogeneous illumination (see fig. 1) and reflexes we apply a high pass filter $H = 1 - B$, where B is a binomial smoothing filter (see fig. 2). Now we determine the first point of the main veins and their initial directions of the leaf interactively. As shown in fig. 1 we can handle leaves with any number of main veins.

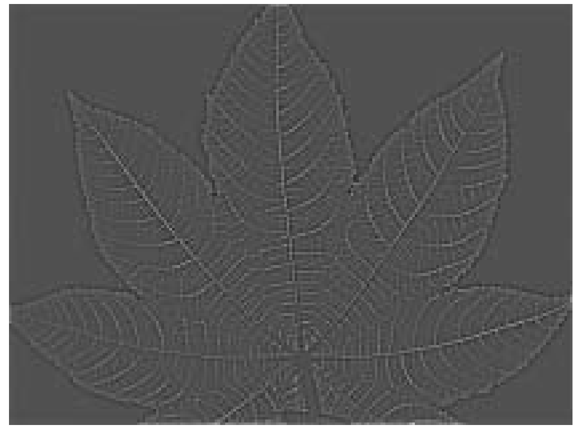

Figure 2: Highpass filtered leaf image.

2.2 General search principle

The search for vein points scans areas A_s of variable width and length in the initial direction and a specified range of evenly spaced angles (see fig. 3 left). All sampled areas are compared by their quality measure, the end point of the best area is taken as new initial point and the direction of the area is the new search direction [3].

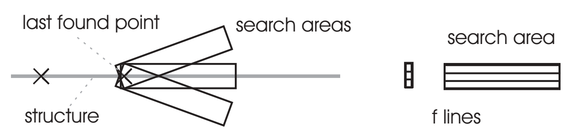

Figure 3: Left: structure and search areas. Right: sum of the sampled lines.

In our examples we use areas with 3 pixels of width. There are several quality measures. For example the sum of grey values in the area, the variance of the lines or the angle between the last and new search direction.

In order to get more robust results it is possible to combine several measures by fuzzy technique [3] which has not been implemented in our approach.

2.3 Main vein search

The next step of the initialization is the search for the main veins. We search each vein separately. As the image of the main veins can change from dark to bright (see fig. 2) we use the variances along the lines of A_s as quality measure and sum them up. The area with the lowest variance is the best one as the grey value profiles are rather smooth along the main veins. Now we use the found points as fulcrums of a b-spline (which we call S_m in the following for the main veins) and get a continuous description of the main veins (see fig. 4). Note that the side veins are still not detected.

The background of the leaf is masked to avoid a continuation of the algorithm in this area.

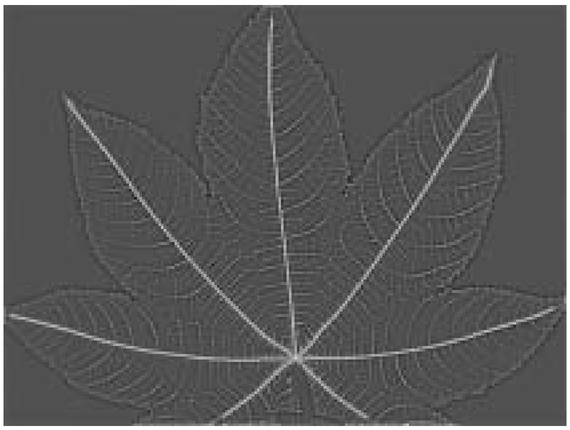

Figure 4: Extracted main veins on a leaf of ricinus comunis.

2.4 Side vein search

In order to find start points for the side vein search we sample the area around the main veins with a b-spline method. The sampling is done along a line normal to the b-spline as proposed in [1] at every whole-numbered b-spline length measured in pixels. This way we get images of the adjacent area of the main veins (see fig. 5).

Then we search for maxima on a line parallel to the main vein. We take all maxima as feasible start points of side veins. From earch maximum we perform the search for a side vein in normal direction to the main vein (which we get from S_m) and convert them into b-splines again (see fig. 6).

In our case we know that the side veins are lines which are brighter than the background. Therefore we sum up the lines of the sampled area (see fig. 3 right) resulting

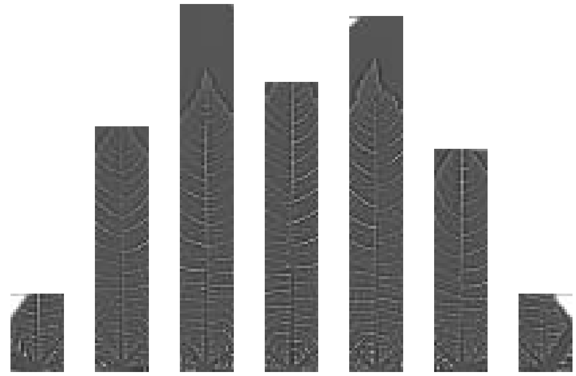

Figure 5: Sampled surroundings of the main veins

in a vector of grey value sums along the lines of the area. The second derivative of each sum vector computed by the discrete Laplacian [1,-2,1] serves as quality measure. Its maximum indicates the most significant vein direction. In this way we only detect bright line-like structures which belong to the side veins (see fig. 6).

This tracking algorithm is very stable, meaning that the side vein search does not necessarily stop at the end of a vein. As shown in fig. 2 the side veins in the central area of the leaf form octagons. Therefore the algorithm will not stop at the end of a side vein but went around in circles. We did not solve this by minimising the range of search angles because introduces new difficulties on strongly bended side veins. To solve this problem we introduced a interactively created mask which labels the area that belongs to each main vein (see fig. 7). We use the constance of the label number as constraint for the side vein search.

3 Experimental results

In order to test the algorithm we applied it to image data. We use byte and short images with 480x640 pixels. Intentionally, we did not correct any of the veins in order to show the performance of the algorithm. Gaps in the main veins to the image boundary occur, when the length of the search area is longer than the distance to the boundary. This is a criterion for the algorithm to stop. In fig. 12 there are some side veins missing because they show no

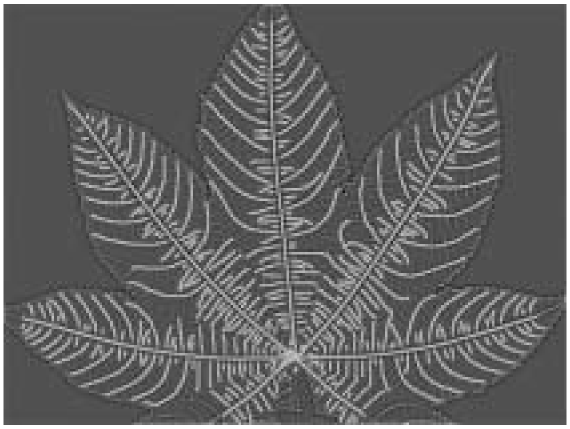

Figure 6: Found main and side veins on a leaf of castor bean.

Figure 7: Labeled image for the side vein search.

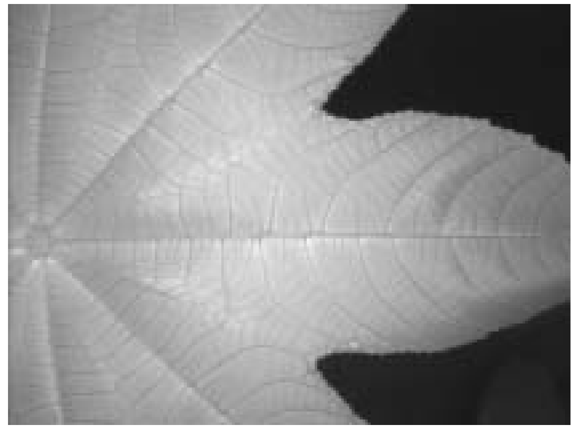

Figure 8: Original image of a castor bean leaf.

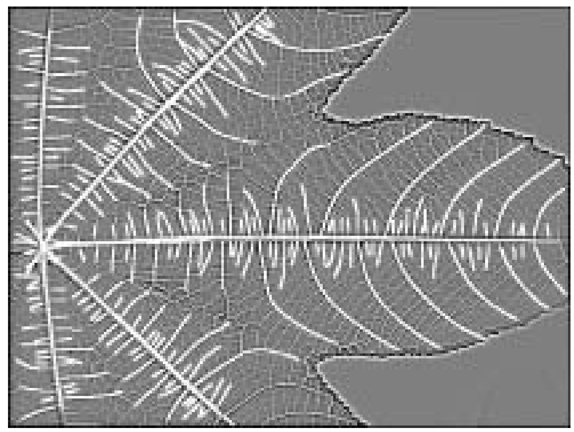

Figure 9: Leaf of castor bean with detected veins.

maximum near their associated main vein.

4 Summary and Outlook

In this paper we presented a robust method for the extraction of veins in plant leaf images. For the detection of veins we use quality measures adapted to the different properties of first and second order veins (2.2, 2.3, 2.4). The end of the search is marked by masks indicating the region in which the veins occur. The proposed algorithm performs well on all image data tested.

Further work should integrate combinations of several quality measures by fuzzy means resulting in a more robust tracking. Moreover we want to introduce a physiological leaf coordinate system. Therefore we need to identify the side veins which reach the leaf boundary.

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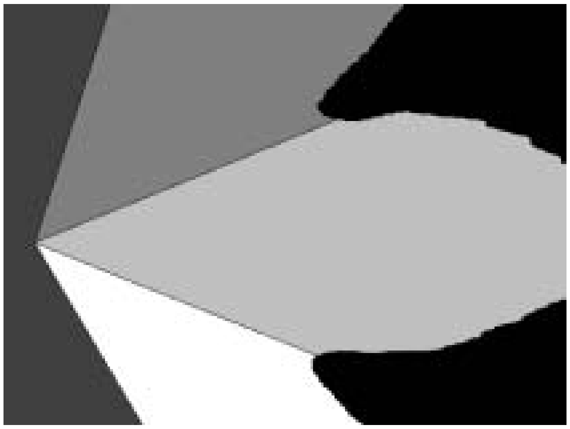

Figure 10: Labeled image for the side vein search.

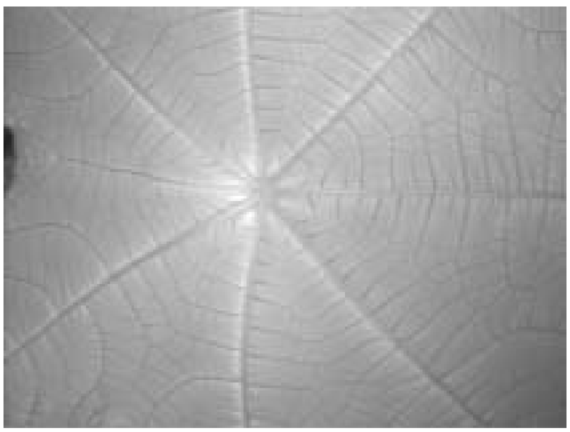

Figure 11: Original image: part of a castor bean leaf.

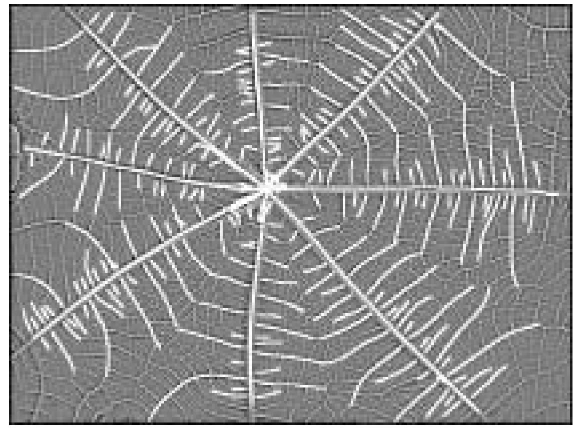

Figure 12: Detected veins.

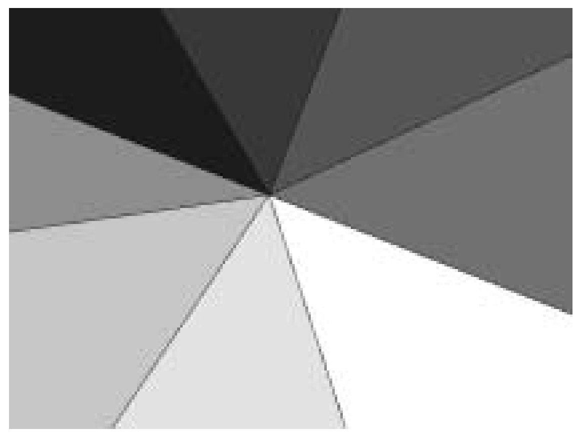

Figure 13: Labeled image for the side vein search.

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