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Machine Learning Techniques for Ontology-based Leaf Classification

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Abstract

Leaf classification, indexing as well as retrieval is an important part of a computerized plant identification system. In this paper, an integrated approach for an ontology-based leaf classification system is proposed, wherein machine learning techniques play a crucial role for the automatization of the system. For the leaf contour classification, a scaled CCD code system is proposed to categorize the basic shape and margin type of a leaf by using the similar taxonomy principle adopted by the botanists. Then a trained neural network is employed to recognize the detailed tooth patterns. The measurement on an unlobed leaf is also conducted automatically according to the method used in botany. For the leaf vein recognition, the vein texture is extracted by employing an efficient combined thresholding and neural network approach so as to obtain more vein details of a leaf. Compared with the past studies, the proposed method integrates low-level features of an image and the specific knowledge in the domain (ontology) of botany, and therefore provides a more practical system for users to comprehend and handle. Primary experiments have shown promising results and proven the feasibility of the proposed system.

1 Introduction

Since the leaf is considered as an important feature to characterize plant species, the study on leaf image retrieval based on contour information has been conducted for a computer-aided plant identification system [1]. In recent years, some research has been done on recognizing plant species with plant components including leaf shape. Nielsen [2], Abbasi et al. [3] and Im et al. [4] obtained some preliminary results on plant recognition and classification by using the shape features of plant leaves. Nielsen [2] built Point Distribution Models (PDMs) for seven different plants and investigated the variability of the models within the same plant species. Abbasi et al. [3] introduced a method for semi-automatic classification of Chrysanthemum leaves through Curvature Scale Space (CCS). Im et al. [4] used a hierarchical polygon approximation representation of leaf shape to recognize the Acer family variety. Systemic investigations on shape based leaf image retrieval have been carried out by Wang et al. [5-7] since 2000. They adopted three shape feature sets including Centroid-Contour Distance (CCD), Moment Invariants (MIs) and Angle Code Histogram (ACH) to represent a leaf shape and then employed a fuzzy integral to fuse these three feature sets. The method was tested on a database containing 830 leaf images from 83 Chinese medicinal plants and encouraging results have been achieved.

However, no attempts have been made to transfer the taxonomy used by botanists to describe the leaf. A system for ontology-based leaf classification, indexing and retrieval is very attractive. The system should support two kinds of retrievals, keywords and "query by an example". For a given query leaf image, the top matched leaf images will be returned based on the terminologies in the database and low level features of the query image.

In this paper, an approach of ontology-based automatic leaf classification is proposed. In Section 2, the ontology used by botanists to describe a leaf is presented. The method of mapping the low-level features to the linguistic terms in the shape branch of leaf ontology is discussed in Section 3. Leaf vein

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extraction is introduced in Section 4. Finally, conclusions are drawn in Section 5.

2 Ontology for Leaf Classification

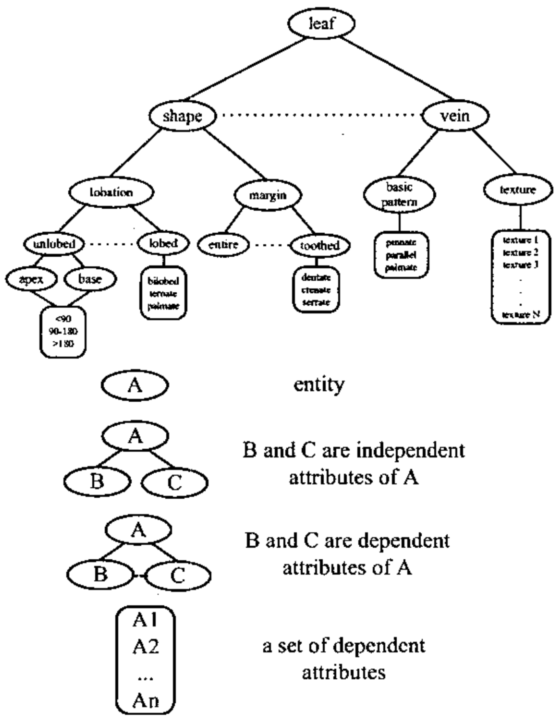


Figure 1. Ontology for a leaf.

An ontology defines a common vocabulary for people who need to share information in a domain, which enables reuse of domain knowledge [8]. Since there is no single well-accepted ontology-design methodology, we built the ontology to describe a leaf with emphasis on the taxonomy commonly used in botany [9, 10] and propose automatic mapping from low level features to the semantic terms. As shown in Fig. 1, ontology consists of two main branches: shape and vein. In the shape branch, the lobation and the margin are two independent and primary properties to characterize the shape of a leaf. That is to say, a leaf could be unlobed or lobed in spite of its margin or vice versa. The unlobed leaves are classified according to their apex and base angles, while the lobed ones are classified according to the number of lobations. The margin could be entire or toothed. Furthermore, the toothed margin contains dentate, crenate and serrate teeth. In the vein branch, there are three basic patterns that are quite related to the basic shape. For example, a leaf with palmate lobation usually has a palmate vein pattern. The textures of high-order veins are useful for recognition.

3 Shape-based Classification of Leaves

A leaf can be assigned to different classes and subclasses according to the ontology shown in Fig. 1. This time-consuming task is usually carried out by human beings in the field of botany. Automatic leaf classification based on machine learning techniques releases the burden from botanists so that they can pay more attention to higher level researches.

3.1 First-Stage Classification – Using the Scaled CCD Code to Recognize Lobation and Tooth

The Centroid-Contour Distance (CCD) curve is a popular representation of shape, in which a two-dimensional shape is converted to a one-dimensional curve by calculating the distances between the centroid and the pixels on the contour [5]. The large scale variation (lobation) and small scale variaton (tooth) of a leaf are both preserved in CCD, but it is hard to classify leaves by comparing their CCDs directly due to the lack of scaling and rotation invariant properties. We proposed scaled CCD code which is scaling invariant and rotation invariant to characterize the leaf shape. The scaled CCD code is obtained by following four steps below:

Step 1: Smooth $CCD(x),\ x=1,...,N$ using normalized Gaussion function $g(x)=\frac{1}{2\sigma^2}e^{-\frac{(x-\mu)^2}{2\sigma^2}}$. The smoothed CCD is

$$MCCD(x)=pconv(CCD,g), x=1,...N, \qquad (1)$$

where $pconv(\ ,\ )$ is the periodic convolution.

Step 2: Segment the CCD using the smoothed CCD, *i.e.*, to find points $n_i, i=1,...,M$, where MCCD crossing CCD, as shown in Fig.2(d). Let the block signal

$$BCCD(x)=\begin{cases}\max(CCD), & CCD(x)>MCCD(x);\\ \min(CCD), & CCD(x)<MCCD(x).\end{cases} \qquad (2)$$

Step 3: Merge the segments according to different scales, that is, let the depth of the gap

$$P_i = \begin{cases} \max[CCD(n_i : n_{i+1})] - \min[CCD(n_{i-1} : n_i)], \\ \qquad if\ BCCD(n_i : n_{i+1}) = \max(CCD); \\ \max[CCD(n_{i-1} : n_i)] - \min[CCD(n_i : n_{i+1})], \\ \qquad if\ BCCD(n_i : n_{i+1}) = \min(CCD). \end{cases}$$

the local radius $R_i = mean[CCD(n_{i-1} : n_{i+1})]$,

and the relative depth of the gap is then defined as

$$G_i = \frac{P_i}{R_i} \tag{3}$$

For each scale $D = 64, 32, 16, 8, 4, 2$,

if $G_i < \frac{1}{D}$, merge the two neighboring segments $CCD(n_{i-1} : n_i)$ and $CCD(n_i : n_{i+1})$.

Step 4: Get a 7-bit scaled code by calculating the number of segments after each merging process, as shown in Fig.2 (i). The first two bits and the 3-6-th bits of the scaled CCD code indicate the basic shape and the teeth of the shape, respectively. The last bit could be regarded as distortion. For example, for the leaf shown in Fig.2 (a), the sum of the first two bits of the scaled code is 8 and the teeth bits are not zero, which means it is a three lobed (ternate), teethed leaf. More samples are illustrated in Fig. 3.

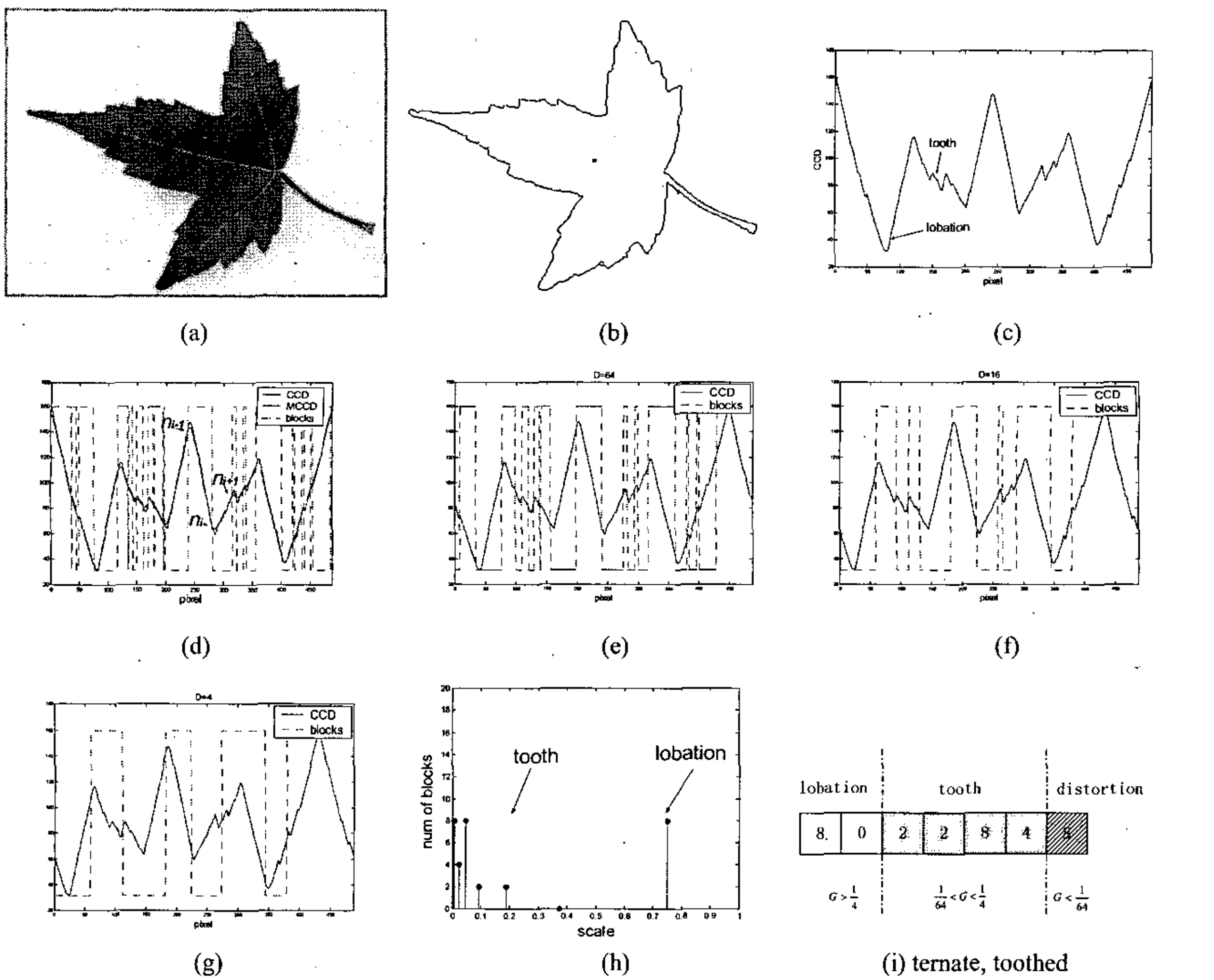
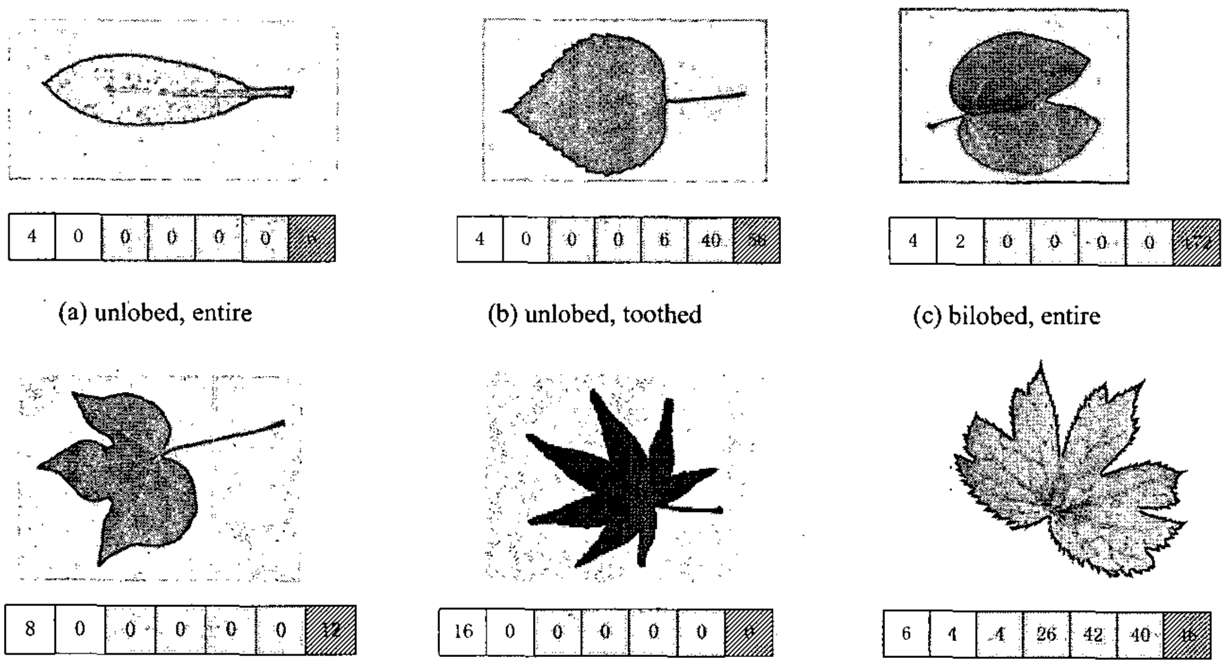


Figure 2. The process to obtain the scaled CCD curve. (a) a leaf image; (b) the centriod and contour; (c) the CCD; (d) the CCD, MCCD and blocks segmented by MCCD; (e, f, g) the segments after merging $G < \frac{1}{64}, \frac{1}{16}, \frac{1}{4}$; (h) the number of segments on the scale space; (i) the scaled CCD code and the annotation.



(a) unlobed, entire (b) unlobed, toothed (c) bilobed, entire

(d) ternate, entire (e) palmate, entire (f) palmate, toothed

Figure 3. Different leaves, their scaled CCD codes and annotations.

3.2 Second-Stage Classification – Using a Neural Network to Recognize Tooth Type

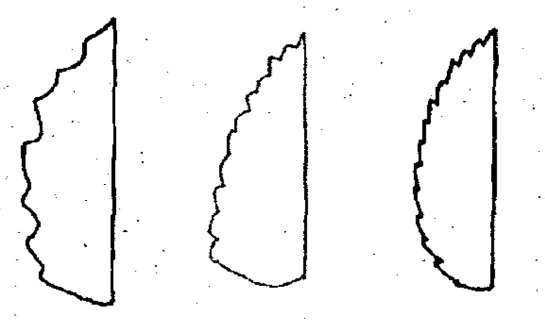


Figure 4. Three types of teeth. (a) Dentate - The leaf has widely spaced teeth that are pointed at their tips, but with concave spaces between them; (b) Crenate - The leaf has blunt teeth with convex sides; the indentations between teeth are somewhat angular, rather than rounded; (c) Serrate - The leaf margin is divided into sharp teeth of approximately the same size, like a saw.

The line drawings of three most common types of teeth with their definitions are illustrated in Fig. 4 [10]. For a leaf which has been classified as a toothed one in the first stage, a trained Feed Forward Neural Network is adopted to recognize the type of its tooth. The scaled CCD approach discussed in 3.1 helps extract the segment of the contour containing the teeth. Different features such as the CCD of the toothed segment, Fourier coefficients of the CCD segment have been used to train a three-layer neural network with a data set which consists of 35 training samples and other 35 testing samples for each category. The results are listed in Table 1. The CCD of the toothed segment achieves the highest correct rate among other candidates, so it is adopted by us for the classification system.

Features of the toothed segment	Input nodes	Hidden nodes	Output nodes	Correct rate (%)
CCD of toothed segment	100	100	3	94.26
Fourier coefficient	64	100	3	85.71
Moment invariant	7	30	3	69.52
Chain code	100	100	3	42.86

Table 1. Different features tested for teeth classification

3.3 Third-Stage Classification - Measurements on Unlobed Leaves

Botanists describe unlobed leaves in more detailed ways using the base angle and apex angle [9]. The base angle is defined as the angle from the vertex to the points where a line perpendicular to the midvein at ¼ of the length of the laminar. The apex angle is the angle from the apex to the pair of points where a line perpendicular to the midvein at ¾ of the length of the laminar. Since the type of the basic shape has been known after the first stage, it is not difficult to measure the two angles. As shown in Fig. 4, first we detect the start of the laminar "A" by analyzing the width of the leaf, find the main axis, and measure the angles.

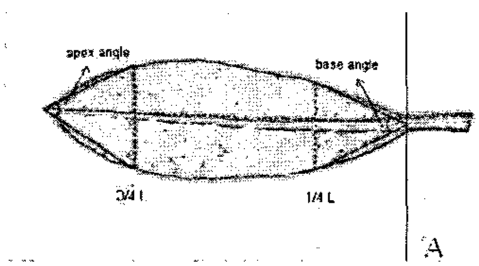


Figure 5. Measurements on the unlobed leaf.

4 Leaf Vein Extraction

As mentioned in Section 2, since the basic pattern of leaf veins depends on the outline of a leaf, textures of the higher order veins are more important for recognition, especially for the leaves with similar shapes. An efficient two-stage approach for leaf vein extraction is as follows [11]. At the first stage, a preliminary segmentation based on the intensity histogram of the leaf image is carried out to estimate the rough regions of vein pixels. This is followed at the second stage by a fine checking using a trained artificial neural network classifier. Ten features distilled from a window centered at the pixel are used as the input to train the classifier. Some vein extraction results are shown in Fig. 6. Thus, two leaves similar in shapes can be classified by detailed vein textures.

(a)

(b)

Figure 6. Examples of leaf sub-images (a) and the extracted veins (b) by using the trained ANN classifier.

5 Conclusions and Future Work

The scheme of an ontology-based leaf classification system has been introduced, wherein machine learning techniques play a crucial role for the automation of the system. Primary experiments show promising results and the feasibility of the proposed system. Considering that some features of leaf cannot be described by linguistic terms, one of the aspects for future work is to combine more low level features with the leaf ontology in order to enhance the classification ability of the system. Another possible aspect is to integrate a relevance feedback scheme into the system, enabling collecting the feedback from botanists so as to refine the classification rules.

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