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Recognition of leaf image set based on manifold–manifold distance

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ABSTRACT

Recognizing plant leaves has been a difficult and important work. In this paper, we formulate the problems by classifying leaf image sets rather than single-shot image, each of set contains leaf images pertaining to the same class. We extract leaf image feature and compute the distance between two manifolds modeled by leaf images. Specifically, we apply a clustering procedure in order to express a manifold by a collection of local linear models. Then the distance is measured between local models which come from different manifolds that constructed above. Finally, the problem is transformed to integrate the distance between pairs of subspace. Experiment based on the leaves (ICL) from intelligent computing laboratory of Chinese academy of sciences, which shows that the method has a great performance.

1. Introduction

When we wander around the fields, we can find lots of plant. However, we rarely know their names. There are about 270,000 plants that have been named on Earth, and many are still unknown yet. Human identify the large number of existing plant species are dreary and time consuming, particularly for those non-expert. On the other hand, plant recognition or classification has a broad application prospective in the agriculture and medicine, and is especially significant to the biology diversity research. But in recent years people have been seriously destroying the natural environments, so that many plants constantly die and even die out every year. The main step of protecting plants is to automatically recognize them and understand what they are and where they come from. To handle such huge information, develop a quick and efficient classification method has become a significant research.

There are several ways to recognize a plant, like fruit, root, flower, leaf etc. And they are three dimensional objects and have complex with the exception of leaf. Leaf classification and recognition is a significant component of automated plant recognition system, because leaf features often contain important information that can help in plant species recognition and we can obtain a great number of leaves easily. A leaf can be characterized by its color, texture, vein structure, and shape. The type of the vein is an important morphological characteristic of the leaf.

In traditional visual recognition task, leaves of interest are trained and recognized from only a few samples. Rashad et al. [1] have used a combined classifier learning vector quantization along with the radial basis function, a small part of leaf can be classified by the proposed system. Hossain et al. [4] proposed a method which works for the plants with broad flat leaves. In this method, the user selects the base point of the leaf and a few reference points on the leaf blades. On the basis of these points, the leaf shape is extracted from the background and a binary image is produced. Zheng et al. [5] extracted leaf vein based on gray scale morphology. The main idea is to look upon the leaf vein as the noise on the leaf surface and adopt the method of noise detection to extract the leaf vein. Lee et al. [10] used the main vein and the frequency domain data by using Fast Fourier Transform methods in conjunction with distance measurement between the contour and centroid on detected leaf images. Hu et al. [19] propose a novel contour-based shape descriptor, called the multiscale distance matrix, to capture the shape geometry while being invariant to translation, rotation, scaling, and bilateral symmetry. Du et al. [13] used a new method of describing the characteristics of plant leaves based on the outline fractal dimension and venation fractal dimension. Larese et al. [28] proposed a procedure for segmenting and classifying scanned legume leaves based only on the analysis of their veins (leaf shape, size, texture and color are discarded). The segmentation is performed using the unconstrained hit-or-miss transform and adaptive thresholding. Several morphological features are computed on the segmented venation.

After extracting leaf image feature, the classification and recognition task often use traditional classifier that based on

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single-shot image, such as k-nearest neighbor, learning vector quantization, probabilistic neural network [20–26], support vector machine, genetic algorithm etc. Although the traditional classifier have achieved a certain level of success under restricted conditions in leaf automatic classification and recognition, more robust object recognition can be expected by using sets as input rather than single image, because an image set offers more information compared with a single image. We can extract many leaves from a photo which is taken from a tree or other plants [3]. The quantity of leaf images for both training and testing can be very large. These leaves appearance changes dramatically under variations in shape, size, texture, etc. Therefore we introduce a novel approach for leaf recognition using multiple leaf image patterns obtained in various views.

For image set classification, existing methods mainly concentrate on the key issues of how to model the image sets and haw to measure their similarity. From the view of set modeling, relevant approaches to image set classification almost fall into parametric or nonparametric representations. Nonparametric methods use more flexible manner to assume the distributions of the set data. Kim et al. [6] represent the image set as a single linear subspace. Wang et al. [12] employ more sophisticated manifold to describe an image set. They use the method of principal angles to capture the similarity of two subspaces. Hakan et al. [15] model each set as an affine hull or a convex hull and match the closest pair of points from two hulls.

In this paper we propose a method of recognizing leaf images based on image sets using manifold to manifold distance. As illustrated in Fig. 1, each class of leaves is enrolled with a gallery image set, and the unknown species are also represented by different probe image sets. We model the leaves from one species as a manifold and calculate the distances between pairs of manifolds, identification is achieved by seeking the minimum distance. First of all, we extract local liner models via clustering from different manifolds which are expressed by various species of leaves. Then calculate the similarity between pairs of local models by principal angle and compute the manifold to manifold distance by integrating the similarities.

2. Problem formulation

In view of the above discussions, we extract shape feature and model the image set as manifold, and then formulate the problem as multi-manifolds learning. Formally, given a leaf database as

$$G = \{X_1, X_2, \ldots, X_n\} \tag{1}$$

where

$$X_i = [x_{i,1}, x_{i,2}, \ldots, x_{i,ni}] \ (i = 1, \ldots, n) \tag{2}$$

express a data matrix of the ith set, and ni define as the number of image samples. As mentioned above, we model each image set X_i as a nonlinear manifold M_i and then extract the local linear models to characterize it, define as

$$M_i = \{L_{i,1}, L_{i,2}, \ldots, L_{i,Ni}\} \tag{3}$$

Here, Ni denotes the number of local models in the ith set. Typically $Ni < < ni$.

Given a probe image set $T = \{L'_1, L'_2, \ldots, L'_l\}$ containing l local liner models of a species whose identity is one of the ni species in the gallery set. We formulate the problem as follows:

$$d(M_i, T_j) = \sum_{i=1}^{Ni} \sum_{j=1}^{l} f_{ij} d\left(L_i, L'_j\right),$$
$$\text{s.t. } \sum_{i=1}^{Ni} \sum_{j=1}^{l} f_{ij} = 1, \ f_{ij} \geq 0. \tag{4}$$

In this general formulation, the manifold to manifold distance comes from a weighted average of pair-wise subspace distance.

3. Feature extraction

In this paper, we extract leaf shape information by Pyramid of Histograms of Orientation Gradients (PHOG) [7]. PHOG is a spatial pyramid extension of the histogram of gradients descriptors (HOG). The HOG descriptor calculates the occurrences of gradient orientation in localized parts of an image (Figs. 2–4).

In the first, the PHOG descriptor extracts canny edges. Then the leaf image is divided into spatial grids at all pyramid levels. After that, orientation gradients are calculated by the Sobel mask. At last, the gradients of each grid are linked together at each pyramid level. In our experiments, we set the number of pyramids $L = 3$ and the bin size $N = 8$, the orientation range is 0–360°.

4. Local liner model construction

To extract local liner models from manifold, the main challenge is how to guarantee the linearity property explicitly [9,27]. In common sense, Euclidean distance is similar to geodesic distance for any two points in a local linear-approximation model. Therefore we employ the deviation between Euclidean distance and geodesic distance to measure the nonlinearity degree in a manifold.

In this thesis, we use the graph-based method of Isomap for approximating the geodesic distances between images in a leaf manifold and employ hierarchical divisive clustering to extract a

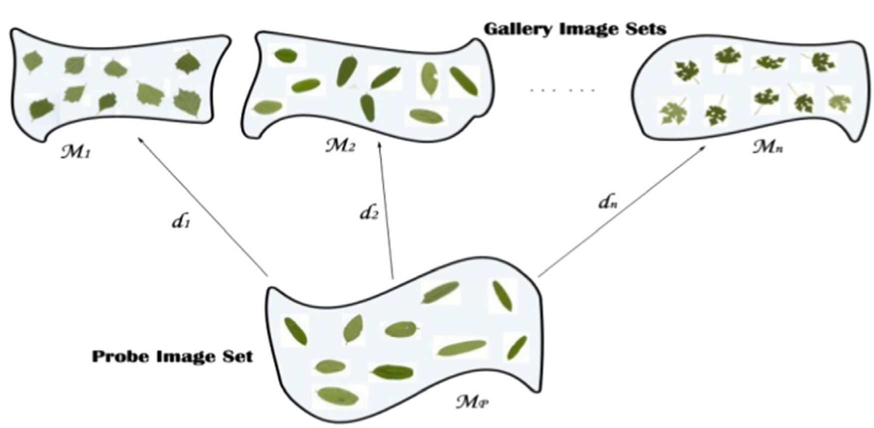

Fig. 1. Leaf recognition based on image sets.