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Individual leaf identification from horticultural crop images based on the leaf skeleton

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ABSTRACT

Complex scenarios make individual leaf identification challenging, such as messy distributions, fuzzy edges, overlapping, and weeds. In this study, we solved this problem by using the skeleton to estimate the locations and directions of the leaves. We propose a segmentation algorithm based on similar tangential direction (*TD*) to retrieve skeletons, and we then use the relative moment and the number of pixels for directions to compute the leaf distribution. Experimental results obtained based on 12 types of leaves demonstrated that our proposed system can automatically identify individual leaves. In addition, our system can obtain robust performance with complex horticultural crop images.

1. Introduction

Recent advances in image acquisition devices and data transmission technology have facilitated the capture of rich horticultural crop images and the transmission of these images to an information center. Leaf identification is a crucial step for obtaining status information from images. If we can recognize leaves automatically in live horticultural crop images, it will be possible to analyze each leaf automatically and to determine the crop status. For example, we may determine the leaf numbers and each leaf's area, before assessing the growth status and dynamic growth processes. Insect pests and crop diseases may change the color of leaves to yellow, brown, or black, or create bites or holes in the leaves. These leaves cannot be detected easily based on an image (Lloret et al., 2011). Thus, if the leaves can be identified, we can analyze the color change regions and missing regions in each leaf as well as the geometry of these regions, thereby acquiring accurate insect pest and crop disease information. However, identifying leaves in an image is a very difficult task because of the following issues: (1) the foreground (target leaves) and the background (such as weeds) of an image are often very similar (Teng et al., 2011); (2) an image often contains numerous leaves, and the luminance and texture features of different leaves are very similar; and (3) the leaves often overlap with each other in an image and the edges between different leaves are often unclear. There are several leaf identification schemes. Some researchers cut the leaves from plants and placed them on a flat panel to simplify the segmentation issue (Nam et al., 2008; Dornbusch and Andrieu, 2010; xiang Dun et al., 2013; G.Larese et al., 2014). These systems are designed primarily for identification or classification, so the extraction algorithms they employ are quite simple. However, this approach will injure the plant and this is not permitted in some cases (Teng et al., 2011).

Many studies have aimed to exploit leaf shapes to constrain the leaf-finding problem (Wang et al., 2003; Caballero and Aranda, 2010; Cerutti et al., 2013b; Du et al., 2007). If it is available, shape information can be used to reduce the computational complexity when finding leaves. However, leaf shape descriptors are not designed to consider the nature of objects (Cerutti et al., 2013a). Thus, due to shape deformation and variation within an object class, a simple rigid model-based approach will usually fail (Sclaroff and Liu, 2001).

Some studies have aimed to extract leaves from simple natural backgrounds, such as soil and residues (Kirka et al., 2009; Guo et al., 2013; Neto et al., 2006). These extraction methods are successful regardless of the background complexity, similarity of colors and overlapping leaf area (Wang et al., 2008).

Some studies have used three-dimensional (3D) reconstructions of plant and depth information to segment leaves (Teng et al., 2011; Quan et al., 2006), but these systems need more than one image to estimate the 3D information. In addition, these systems

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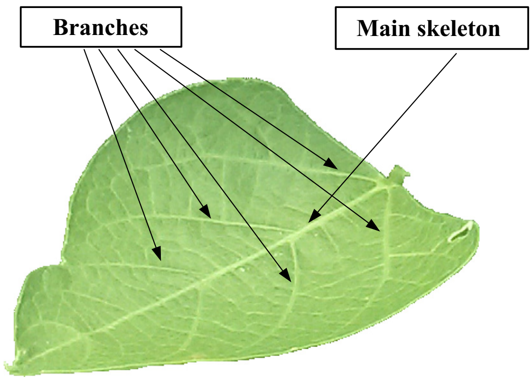

Fig. 1. Main skeleton and branches of a leaf.

are not fully automated and some user intervention is still required.

Jianlun et al. used the Otsu and Canny operators to segment the area of the target leaf (Wang et al., 2013) from a complex background. However, their algorithm could only segment a single leaf in a leaf image.

In the present study, we aimed to identify individual leaves automatically and to obtain leaf distribution information from images of live horticultural crops. We refer to the longest and thickest venation in a leaf as the main skeleton, and the other venations as branches, as shown in Fig. 1. There are various types of leaves in nature and they have different boundary curves, as shown in Fig. 2, but many types of leaves have the following characteristics: (1) the main skeleton and skeleton branches are approximately linear; (2) the skeleton branches incline and connect with the main skeleton; (3) the light intensity of the pixels in the main skeleton and skeleton branches is higher than that of the other leaf pixels; and (4) the surfaces of the leaves are smooth. In this study, we employed these four characteristics to identify individual leaves automatically and to obtain leaf distribution information. Our system has the following advantages: (1) it can identify leaves automatically; (2) the images are captured directly from live horticultural crops, which means that our system does not injure them; (3) we only require that the captured images have the four characteristics, which makes the system more adaptable to complicated crop images; and (4) the images can contain numerous leaves and our system can identify individual leaves as well as determine the leaf distribution. In addition, our system also has the following limitations: (1) the leaf skeleton should possess the four defined characteristics; and (2) the individual leaves cannot be fully segmented from horticultural crop images. However, our system can identify the leaf skeletons, leaf roots, and leaf direction, which can represent the actual leaf area. Our system may also be used for further research, such as estimating the leaf area and obtaining information about diseases and insect pests.

The remainder of this paper is organized as follows. In Section 2, we present the horticultural crop images collection and propose the individual leaf identification system based on the leaf skeleton. In Section 3, we present evaluation of our system based on experiments. Finally, we conclude our study in Section 4.

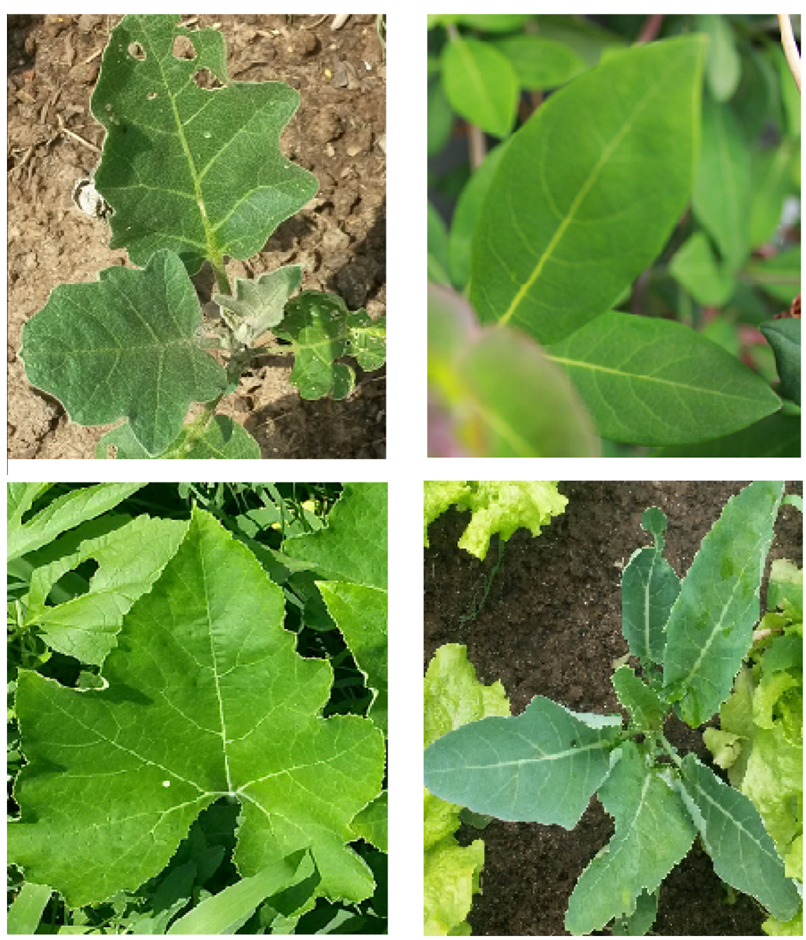

Fig. 2. Samples leaves with characteristics of the leaf skeleton.