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Disease detection of Cercospora Leaf Spot in sugar beet by robust template matching

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ABSTRACT

In a multidisciplinary scheme linking computer science with agricultural engineering, a novel approach based on orientation code matching (OCM) for robust, continuous, and site-specific observations of disease development in sugar beet plants is presented. Differing from conventional plant disease detection approaches, we introduce the robust template matching method of OCM in this paper to not only realize continuous and site-specific observations of disease progress, but also to demonstrate its excellent robustness for non-rigid plant object searching in scene illumination, translation, slight rotation, and occlusion changes. Furthermore, a single-feature two-dimensional xy-color histogram is proposed and input into support vector machine (SVM) classifier for pixel-wise disease classification and quantification. Experimental results with high precision and recall rates demonstrate the feasibility and potential of our proposed algorithm, which could be further implemented in real sugar beet fields with robust detection and precise quantization of foliar disease development, for better analysis of disease mechanism and optimal fungicide-spraying management.

1. Introduction

Sugar beet is a commercial plant, which is second only to sugarcane as a source of global sugar production. However, foliar diseases in sugar beet plants often cause significant reduction in both quality and quantity of beet sugar and represent an economic loss for sugar producers. In particular, Cercospora Leaf Spot (CLS) is the most prevalent and destructive foliar disease in sugar beet worldwide, and leads to major losses of gross beet sugar yields and less income for sugar factories and growers (Shane and Teng, 1992). Therefore, this large economic factor is the driving force for detection and continuous quantization of CLS in sugar beet plants to optimally determine the foliar fungicide application schedule to reduce losses from CLS.

In general, the traditional method to decide the timing and frequency of CLS fungicide spraying is to monitor a field for assessing disease severity by naked eye observations of disease specialists. Then, the decision of fungicide spraying will be made mainly depending on the combination of disease severity and local climate conditions (Jones and Windels, 1991). However, this task of field monitoring is a labor-intensive, costly, and somewhat subjective activity in large-scale field. Furthermore, farmers in underdeveloped agricultural countries may have to travel long distances to seek well-trained experts' advices, a process that may be time consuming and expensive, if even possible.

To overcome these problems, inexpensively automatic detection and quantization of plant disease are desirable for precise plant protection under field condition. In recent years, imaging techniques have been extensively explored for plant disease study because of their merits of noninvasive, rapid, continuous, and precise measurement capacities. Especially, visible spectrum sensing (400–700 nm) such as RGB color image, as well as some invisible spectrum sensing techniques of multispectral imaging (separate the wavelengths into numerous bands) and hyperspectral imaging (finer spectral resolution), are currently gaining much interest for their well-demonstrated results in detecting, categorizing, diagnosing, and quantizing plant diseases.

For visible sensing-based RGB images, Polder et al. (2007) used RGB and photosynthetic efficiency (PE) images for early prediction of the disease outbreak in cabbage leaf by comparing the pixel-wise image registration schemes of penalized likelihood warping with robust point matching methods. This method can handle the leaf warping and slit overlapping problems during leaf growth processes. Camargo and Smith (2009a) developed a disease segmentation algorithm for diverse crop disease identification by determining the threshold value according to the position of a

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set of local maxima in the histogram. This algorithm can cope with large intensity distributions of the image set. Furthermore, Camargo and Smith (2009b) conducted a continuous study using a support vector machine (SVM) to classify different disease causing agents in cotton crops. A set of features, such as shape, textures, and fractal dimension, were extracted from disease regions and a best classification model with a classification rate of 93.1% was achieved via cross-validation. To improve the accuracy and stability of a classifier model for disease classification, Tian et al. (2012) developed an SVM-based multiple classifier system (MCS) with color, texture, and shape features to categorize different leaf diseases in wheat plants. An improved accuracy rate of 96.16% was demonstrated for the performance of the MCS compared with that of other pattern recognition methods.

In addition to these RGB color image-based methods, spectral imaging has also been shown as a promising way to detect specific spectral reflectance for a particular disease of a given plant species (Chaerle and van Der Straeten, 2000). Kobayashi et al. (2001) employed multispectral radiometer for the identification of panicle blast in rice, and showed that further airborne multispectral scanners may be effectively extended by the spectral range selected. Rumpf et al. (2010) used hyperspectral imaging to detect disease at an early stage and distinguish different pathogens caused leaf diseases in sugar beet plants. Mahlein et al. (2012) also introduced a hyperspectral imaging for detection, differentiation and quantification of diseases in sugar beet based on small-scale analysis, which could facilitate detailed description and understanding of disease development.

Furthermore, some researchers designed imaging systems by combining different optical sensors with their complementary advantages to provide more comprehensive disease analysis. Polder et al. (2010) evaluated the performance of four proximal optical sensors (RGB color imaging, spectrophotometer, spectral imaging and chlorophyll fluorescence imaging) for detecting tulip breaking virus (TBV) in tulips. Moshou et al. (2005) designed a multi-sensor fusion disease detection system based on hyperspectral and multispectral fluorescence imaging sensors for detecting diseases in arable crops under field condition.

In this study, we focus on exploring a robust and precise algorithm for continuous CLS quantification in sugar beet under natural daylight conditions without any artificial illuminant. Besides, we chose to use easily accessed RGB images with our long-term target to develop a cost-effective, easy-operated and portable disease evaluation system, which can be used in practical field by both specialists and farmers. Moreover, we propose a novel template matching-based disease detection algorithm, which mainly consists of the following two frameworks: first, a robust template matching scheme called orientation code matching (OCM) (Ullah et al., 2001; Ullah and Kaneko, 2004), which has shown its excellent performance in a wide range of applications such as visual control (Hutchinson et al., 1996; Papanikolopoulos et al., 1993), medical imaging (Bardinet et al., 1996), surveillance (Howarth and Buxton, 1996), intelligent transport system (Frank et al., 1996), optical flow computation (Ullah and Kaneko, 2003), stereo vision sensor (Ohmura et al., 2010) and other practical applications, is firstly introduced in this study for tracking foliar disease in plant. To continuously observe and study disease development on leaves in both temporal and spatially coherent manners, it is always difficult to handle the changes in both external environment (illumination variations and camera vibration) and internal plant circadian growth (leave translation, small rotation, and occlusion). However, the problems are simplified by using the OCM method, which is capable of providing robust, continuous, and site-specific plant observation over time based on its template matching scheme; second, a pattern recognition approach of SVM was further employed along with a feature of two-dimensional (2D) xy-color histogram, for pixel-wise detection and quantization of plant disease. In other words, this study demonstrates the promising potential to observe temporal and spatial foliar disease changes in plant health.

The remainder of this paper is organized as follows. Section 2 describes the materials and the proposed method mechanism. Section 3 presents the experimental results, and Section 4 concludes with a discussion of the main points of this research and future work. Since we evaluate the proposed algorithm under both laboratory and field conditions, each section consists of two subsections for showing the related work of each condition.

2. Materials and methods

2.1. Experimental treatment

2.1.1. Plant cultivation

2.1.1.1. Laboratory experiments. Sugar beet plants (cv. Amaibuki, 2004; Nippon Beet Sugar Manufacturing Co., Ltd., Japan) were cultivated in ceramic pots (∅31 cm) at 25/23 °C (day/night), 15% relative humidity (RH), and with the help of daily water spraying on the leaf surfaces to improve RH. The plants were watered as necessary and fertilized every two weeks with 200 ml of a 2% solution of fine powder HYPONeX (HYPONeX Co., Ltd., Japan).

The foliar disease CLS is caused by the fungus *Cercospora beticola*, which survives on infected crops, in the form of residual spores (conidiophores) and stromata. Under favorable conditions (especially in high temperature and humidity), spores will germinate and penetrate the leaf surface and damage the photosynthetic apparatus of a leaf, and early symptoms will often appear as isolated leaf spots. The individual leaf spots are nearly circular and tan to light brown with dark brown to reddish purple borders. As the disease develops, individual spots will coalesce and heavily infect leaf tissue by expanding their size.

In laboratory experiments, *C. beticola* was infected by manually sprinkling the infected leaf residual on the surfaces of healthy plant leaves at the vegetative stage of sugar beet plants. Subsequently, the infected plants were placed in a plastic greenhouse with 90% RH at 25 °C (day/night) for two weeks to produce conidiophores and experience the incubation period.

2.1.1.2. Field experiments. Our field experiments were conducted in a test field which locates at Central Agricultural Experiment Station, Naganuma, Hokkaido, Japan. Sugar beets (cv. Amaibuki) were seeded on March 18, 2013 and transplanted into the field on May 9, 2013. The plants were naturally cultivated under field condition. Meanwhile, *C. beticola* was infected naturally without artificial inoculation.

2.1.2. Experimental configuration

2.1.2.1. Laboratory experiments. A weeklong experiment was conducted to assess disease changes in sugar beet leaves under laboratory condition. The experimental system was placed next to a window to utilize natural daylight and simulate the outdoor sunlight conditions. The RGB plant images with 640 × 480 resolution were captured by a CMOS camera (CMOS130-USB2, Fortissimo Co., Japan), which was mounted on a horizontal beam supported by two vertical poles to achieve a constant camera height of 1.9 m above the plant. The top-view images were captured at 1-h intervals. An indoor fluorescent lamp (15 W, 5000 K, FL15EX-N-A, Hitachi Co., Japan) was used as the light resource when capturing plant images during night periods (17:00–6:00).

2.1.2.2. Field experiments. A five-day field experiments were implemented under natural conditions. The experimental system was