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Rice heading stage automatic observation by multi-classifier cascade based rice spike detection method

Xiaodong Bai[a], Zhiguo Cao[b,*], Laiding Zhao[a], Junrong Zhang[a], Chenfei Lv[a], Cuina Li[c], Jidong Xie[a]

[a] School of Telecommunication and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
[b] National Key Laboratory of Science and Technology on Multi-Spectral Information Processing, School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China
[c] Meteorological Observation Centre of China Meteorological Administration, Beijing 100081, China

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ABSTRACT

The rice heading stage is an essential phase of rice production as it directly affects the rice yield. This paper transforms the issue of rice heading stage automatic observation into the problem of rice spike detection and proposes a new method for automatic observation of the rice heading stage. Rice spike detection is achieved using a new multi-classifier cascade method comprised of the following steps: First, SVM with color feature as input is utilized to distinguish the rice spike image patches from the background patches (leaf, soil, water, etc.); Second, a gradient histogram method is applied to remove the yellow leaf patches from consideration; Third, a convolutional neural network (CNN) is utilized to further reduce the false positive rate. The arrival of the rice heading stage is determined by the number of the detected spike patches. To evaluate the proposed method, it was applied to the automatic rice heading stage observation of six image sequences collected by the designed observation device between 2011 and 2013. In the experiment, the proposed method produced similar results to the conventional manual observation method in determining the arrival of the rice heading stage. The differences between the proposed method and manual way were within two days. Experiments demonstrated that the proposed method is an effective approach of automatic observation of the rice heading stage in paddy fields and can be utilized to replace the manual observation.

1. Introduction

Rice is one of the most important crops in the world. About 40% of the world population consumes rice as a staple food. Chinese rice cultivation accounts for 30 million hectares, approximately 27% of the nation's agricultural land (Li et al., 2013; Zhou et al., 2010). China takes the first place in rice production and consumption in Asia. With the problems such as calamitous climate, global warming, plant diseases and insect pests, rice yield growth continues to grow but at a sluggish pace(Bannayan and Sanjani, 2011; Korres et al., 2017; Sarker et al., 2014). Accurate observation of rice growth stages would improve and modernize rice cultivation by providing guidance to growers regarding fertilizer application, irrigation, pest control and other practices to enhance yield(Fageria, 2010; Ishii et al., 2011; Knezevic et al., 2009). In addition, growth stage observation is an integral component of phenological observation. It can be utilized to research the time characteristic of carbon exchange between the atmosphere and the terrestrial biosphere(Boschetti et al., 2009; Sakamoto et al., 2012). Given the importance of crop growth stages, rice growth stage observation has been the hotspot in the fields of agricultural production, management and agricultural meteorology(Counce et al., 2000; Itoh et al., 2005). During the whole rice growth process, the rice heading stage is the most important period as it exerts substantial influence on production output. However, the rice heading stage is a high incidence period for plant diseases and insect pests, such as chilo suppressalis and rice planthopper. After the arrival of rice heading stage, growers must perform corresponding farming activities such as water management and foliar fertilizer to improve the seed setting rate and rice yield (Ryu et al., 2011). Furthermore, rice heading stage observation can also be applied to the rice growth model to improve the accuracy of rice yield prediction and provide reliable information to inform macro-level government decision-making (Takai et al., 2006).

At present, rice growth stage observation in China still relies on traditional manual observation. The conventional method relies on the observer's sampling observations according to the definitions of rice growth stages in "The Agricultural Meteorological Observation Specification" (China Meteorological Administration, 1993). Actually, the conventional method of manual observation has many weaknesses,

* Corresponding author at: No.1037 Luoyu Road, Wuhan 430074, Hubei, China. Phone: +86 027 87558918; Fax: +86 027 87543130.
E-mail addresses: xdbai@njupt.edu.cn (X. Bai), zgcao@hust.edu.cn (Z. Cao).

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such as high labor intensity dependence, non-quantitative standards, the subjectivity of the individual observer, discontinuous observation and crop organ damage (Yu et al., 2013). Thus, manual observation cannot meet the needs of modern agricultural production. This situation makes it imperative to research methods of automatic observation of crop growth stages.

Computer vision technology is an attractive alternative approach to the task of automatic crop observation since it is a low cost, visualized and non-contact manner (Hemming and Rath, 2001). Currently, computer vision technology has many practical agricultural applications including physiological status estimation (Liu and Pattey, 2010; Sakamoto et al., 2012), weed identification(Onyango and Marchant, 2003), fruit grading and picking (Bac et al., 2017; Ejvan et al., 2003; Omid et al., 2010), pest detection (Ebrahimi et al., 2017) and disease detection (Bai and Li, 2011; Pugoy and Mariano, 2011).

The most obvious characteristic of the rice heading stage is that rice spike will expose from the flag leaf at rice heading stage. The rice spike is usually of a bright yellow color compared to the rice leaves. Therefore, rice heading stage automatic observation can be transformed into a process of rice spike detection using computer vision. In other words, the arrival of the rice heading stage can be identified when a sufficient number of rice spikes are detected in a rice image. However, even the rice spike detection from a rice image captured in the paddy field is challenging. First, the initial size of the rice spike is relatively small at the onset of the rice heading stage. Besides, the leaf tips will turn yellow during the hot and dry weathers which frequently occurs in China. Consequently, the transition region between the leaf tip and the middle of the leaf may also has a bright yellow color. Hence, the color feature may not be sufficient to identify a rice spike in rice images. Additionally, the digital camera must be positioned at a proper height to ensure that a sufficient number rice plants are captured in the image to accurately characterize the growth status of the rice population. However, high camera position will reduce the spatial resolution of the images. And then, the texture of rice spike will be slightly degraded. Furthermore, the individual differences of rice spikes and visual obstructions from thick leaves render the shape cue unstable, further complicating the rice spike detection efforts.

There have been several excellent and interesting researches on the task of rice spike detection and measurement. Duan et al. (2015) presented a new method for automatically determining the number of spikes of pot-cultured rice plants by analyzing the rice plant images taken from multiple angles. However, this method only can be used for pot-cultured rice plants, since it requires a specialized light source and image background to ensure its well performance. Huang et al. (2013) adopted a dual-camera imaging unit to collect the rice spike images and realized the spike length measurements. In their research, identification of the spike neck and path extraction were conducted on the rice spike images. In addition, Liu et al. (2010) analyzed the hyperspectral reflectance of rice spikes obtained under wavelengths of 350–2500 nm using a portable spectroradiometer in the laboratory. Finally, they proposed a neural network and principal components analysis based method for discriminating different levels of fungal infection in rice spikes. The above two studies primarily focused on the measurement of the individual rice spike. These methods cannot be utilized to rice spike detection in images captured in the paddy field. To the best of our knowledge, the research on the rice spike detection from the images taken in the paddy field, especially by the common and low-cost visible light camera, has not been previously reported.

In this paper, we propose a new method of automatic observation of the rice heading stage. In the proposed method, we transform the problem of heading stage automatic observation into the process of rice spike detection and put forward a new multi-classifier cascade method for rice spike detection. To accurately and comprehensively describe the characteristics of rice spikes in images, not only the traditional visual features of rice spike such as color and gradient but also the convolutional neural network (CNN) based automatically learned features are utilized in our research. First, a support vector machine (SVM) with color features as input is employed to distinguish the spike image patches from the background patches (non-spike). Then, a gradient histogram method is applied to remove the yellow leaf patches from consideration. Finally, the CNN is utilized to further reduce the false positive rate. Experiment results demonstrate that the proposed multi-classifier cascade method can effectively distinguish rice spikes from background in images. In addition, comparison experiment between the proposed rice heading stage automatic observation method and human observation has been carried out to verify the feasibility and validity of the proposed method.

The rest of the paper is organized as follows. Section 2 details the rice growth observation equipment and the theory of the presented heading stage automatic observation method. Section 3 provides the experimental results of applying our method to rice spike detection in rice images. As mentioned, performance comparison of the performance of the proposed method and manual observation approach were also carried out and discussed. Finally, the paper's conclusion is delivered in Section 4.

2. Materials and methods

2.1. Data collection

The rice images used in our research were captured in Jiangxi Province, China (28.30N, 115.58E), where rice (cultivar: Jiayu NO.948) was grown. Jiayu NO.948 is a type of conventional indica rice that is widely cultivated in southern China. The planting time and cultivation mode were identical to those of local custom. Moderate amounts of herbicide were used to remove the weeds such as duckweed and water hyacinth. As seen in Fig. 1(a), the image acquisition device was directly equipped in the paddy field. Two Olympus E-450 cameras were used to collect the rice images. They were mounted in the protective cover depicted in Fig. 1(b) at a height of five meters above the ground. The cameras were set to the full automatic mode to enable the cameras to adapt to all the lighting conditions of the paddy field. The two cameras were independent of each other in actual observation. Their focal lengths of were set to 25 mm and 14 mm, respectively. The observation areas captured by the cameras were approximately 20 m^2 and 54 m^2. The resolution of all the original images was 3648 × 2736. The cameras photographed their respective fixed regions of the paddy field at 10:00, 12:00 and 14:00 h every day using the image acquisition card in Fig. 1(c). The obtained images were transmitted to a remote computer using 3G data transmission and the antenna pictured in Fig. 1(d). As the whole system was erected outdoors, it was powered by solar panels, as shown in Fig. 1(e). Rice images captured form 2011.6.4 to 2013.6.12 were utilized in our experiment.

2.2. The proposed rice heading stage automatic observation method

The proposed method for rice heading stage automatic observation is based on the fact that sufficient rice spikes will arise from the flag leaf after the arrival of the rice heading stage (China Meteorological Administration, 1993). In this paper, we transform the problem of rice heading stage observation into the rice spike detection from rice images. The proposed method identifies the reaching of the rice heading stage when enough rice spikes were detected. Fig. 2 demonstrates the whole flowchart of the proposed rice heading stage observation method. In the following section, the whole theory of the proposed method is presented. The sign with two parallel short lines in Fig. 2 indicates the parallel processes.

2.2.1. Rice spike detection based on color feature and SVM classifier

As descripted in Section 1, it is not sufficient and reasonable to detect rice spikes using color feature along. However, color feature is an essential cue to distinguish the rice spike from background even for