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Multi-template matching algorithm for cucumber recognition in natural environment

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ABSTRACT

The automatic recognition of cucumber target within its cultivating environment is one of the key techniques for the cucumber harvesting robot. Since cucumber grows in the complex environment and its color is similar to that of branches and leaves, it is quite challenging to achieve high identification accuracy when employing algorithms based on color features, image segmentation and shape features. Adopting spectroscopy can simplify the algorithm. However it increases the complexity and cost of the robot system. The multi-template matching method was proposed to solve this problem in this paper. A multi-template matching library, which contained 65 cucumber images, was established based on the statistical parameters of the matured Radit cucumber, by proportional scaling the standard cucumber image with step of 0.1 in the range of [0.8, 1.2] and rotating with step of pi/36 in the range of [−pi/6, pi/6]. To identify the cucumber in the visual field of the robot, cucumber templates in the library are used to calculate the matrix of normalized correlation coefficients (NCC) with the target image, one after another. If the maximum NCC is above the threshold, there is the target cucumber in the image frame. Otherwise, there is no target in the visual field. To verify the algorithm, 100 photos of the Radit cucumber with different size and angle were sampled in the test. The results indicated that cucumbers were correctly recognized and positioned in 87 images. Cucumbers which were correctly recognized but with picking position deviation appeared in 11 images. Cucumbers were not found in two images. In general, the correct recognition accuracy is 98%, with 11% fault position.

1. Introduction

Cucumber is widely cultivated because of its delicious taste, short vegetative cycle and high economic returns. Matured cucumbers should be harvested in time because of their short maturity stage. Late harvest will reduce the quality of the fruits and slow the mature of the next generation. Therefore, it is necessary to develop cucumber harvesting robot to realize efficiently automatic harvest (Van Henten et al., 2003, 2009). And the automatic recognition of cucumbers in their growing environment is one of the key techniques to achieve the automatic harvesting of cucumbers.

One of the common ways for target recognition is exploring the obvious color difference between the region of interest (ROI) and its background. The color depth difference between fruits and branches was used to identify cucumber target in the natural environment (Yuan and Zhang, 2006). In the training samples, the RGB components of the fruits and the background were extracted. Then the Bayes classification discriminant model was employed, achieving the accurate rate of 73%. Furthermore, Yang et al. (2007) enhanced the image based on the combination of RGB components and segment processing, which increased the contrast ratio between the object and its background. Then the enhanced image was taken as a knowledge system for the construction of knowledge reduction algorithm based on rough sets theory. The colors of the image were set as the conditional attributes and the seven standard colors were set as the decision attributes, which composed the classification decision table. The algorithm can segment the cucumber image taken from the greenhouse with quite high edge continuity and signal-noise ratio. Zhang et al. (2007) extracted the blue component and saturation level of the object and background from the image samples, using the segment and identifying algorithm based on fusion of multiple color spaces. The extracted information was input into the BP network as training data. The trained BP network can segment cucumber object from its background with accuracy of 76%. Qiao et al. (2009) simplified the color image into binary image using R and G components thresholds, exploiting the color depth difference on R and G components between the cucumber and its surrounding stems and leaves. After eliminating the leaves in the background by

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erosion and dilation operations, the cucumber was abstracted according to the circularity feature.

Different from most fruits and vegetables, the matured cucumber has similar color with the branches and leaves, which makes it challenging to identify them by machine vision. While in the images captured by spectroscopy, the cucumber and branches have great gray difference, which is favorable for recognition. Kollenburg et al. (1997) added an optical filter to the conventional vision system, which makes it quite easy to separate cucumber from the background and figure out its position, according to the moisture content and reflecting differences. Kondo et al. (1994) combined monochrome camera and optical filters with wavelength of 850 nm in their cucumber harvesting robot, which could recognize the cucumber in the spectral images. This kind of image acquisition method is featured of high efficiency for its simple processing algorithm requirement. Additional to the optical filter, Li et al. (2008) and Yuan et al. (2011) added a high-power backlighting to mitigate the influence caused by the natural light conditions, which improved the cucumber recognition accuracy to 83.3%. Wang et al. (2011) tried the Near Infrared Reflectance Spectroscopy (NIRS) image segmentation, with wave band from 690 nm to 950 nm. Test of 30 samples showed the accurate rate of 100%.

In addition, it is effective to identify cucumbers by their shape features, since image processing can get preferable cucumber features determination (Van Eck et al., 1998). Wang et al. (2012) adopted pulse coupled neural networks to detect the cucumber and separate it from the background by using mathematical morphology. The least square support vector classifier was used to recognize the cucumber with four geometric feature values and three texture feature values. The correct recognition rate reached 82.9% among the 70 cucumber images. A segment method combining color features with texture features was proposed by Li et al. (2009). Noise was eliminated by color in RGB space according to the CIE-XYZ color model and chromaticity diagram. Then the texture features of entropy and energy were extracted by the gray-level co-occurrence matrix (GLCM) to separate the fruit from background. The recognition rate reached 92% in the high-wire cultivation system (Yang et al., 2013). Meanwhile, Wang et al. (2010) simplified the pulse-coupled neural network model for optimal segmentation by reducing the number of parameters of PCNN. Furthermore, the local standard deviation was utilized for adjusting the connection strength coefficient adaptively. The experimental results showed that the average rate of correct segmentation reached up to 82.4%. Jin et al. (2013) put the information of image samples into the module of iterative-RELIEF, which exports a weight for each feature. Then, the information of image samples with weights was put into the training module of relevance vector machine (RVM). The developed image classifier could be used to predict the categories for images containing a cucumber. The recognition rate was up to 80%.

The difference between the cucumber and its background is obvious in the near infrared spectroscopy. However, the cost, energy consumption and complexity of the robot increased because of the deployment of filters and high-power light. Meanwhile, it is difficult to realize high recognition rate just depending on color features, image segmentation and features extraction (Wang et al., 2010; Jin et al., 2013). Template matching is the most favorable machine vision method in industry applications. But each individual may have different feature parameters in terms of cucumbers, which will yield very low target identification accuracy with simple template matching method. A normalized description method for standard cucumber image was proposed in this paper. The multi-template library derived from standard image was constructed through the transformation of scale and angle. Then cucumbers were recognized from 100 image frames using the multi-template matching method, with a quite acceptable accuracy of 98%.

2. Materials and methods

2.1. Cucumber, equipment and image acquisition

2.1.1. Object cucumber

The subject of this research is Radit cucumber, which is suitable to be cultivated in greenhouse in early spring and autumn. The Radit cucumber is parthenogenesis and floriferous. Each branch can bear 3–4 fruits and the matured cucumber is in length of 12–18 cm. The Radit cucumber is widely favored because of its high productivity, high quality, aesthetics shape and appearance. The average selling price is 20% higher than other species. The samples used in this paper were planted in the modern greenhouse on the campus of Zhejiang University of Technology.

2.1.2. Equipment and image acquisition

The test equipment included a color camera, a laptop computer and MATLAB. The camera is Canon PowerShot SD1200 IS, with functions of auto focus and auto exposure compensation. ThinkPad X220 with windows 7 operating system and MATLAB calculating environment was adopted as the image collecting, storing and processing platform, which has 4 GB RAM, Intel Core 2 i5-2410M CPU (2.3 GHz) and 64 GB SSD + 250 GB hard disk.

2.2. Construction of multiple-template library

In the natural environment, the cucumbers appear as drooping posture because of the gravity. But they are not absolutely downward. Also, the size of cucumbers is different from each other during different growth stages. Even if all of them are matured enough for harvesting, they are not consistent with each other in size and deflecting angle. Considering the growth angle and size difference of cucumbers, the cucumber standard image was obtained through statistics from a large amount of samples (Qi et al., 2011), by image enhancement, thresholding and morphological operations, shown in Fig. 1. A series of cucumber templates were generated through the transformation of scale and angle from the cucumber standard image, which constituted the multiple-template library.

2.2.1. The scale transformation

In the natural environment, the length range of matured Radit cucumber is [12 cm, 18 cm]. So the standard cucumber shape scale was set as 15 cm. And the range of the scale transformative coefficients was defined as [0.8 1.2], where 1.0 means the standard cucumber. The scale transformation can be executed in the spatial domain on the cucumber standard shape. The transformative formula is:

$$M_{scale} = S \times M \tag{1}$$

where M stands for the standard cucumber boundary, S is the scale coefficient and M_{scale} denotes the shape after the scale transformation.

The cucumber shape boundary (x, y) converted to $(x^*,\ y^*)$ by the scale transformation can be expressed by:

$$\begin{bmatrix} x^* \\ y^* \end{bmatrix} = S \times \begin{bmatrix} x \\ y \end{bmatrix} \tag{2}$$

Scale transformation is applied on standard cucumber shape, in which S changes from 0.8 to 1.2 with step of 0.1. So there will be five scale transformation coefficients, shown in Table 1. The cucumber boundaries under different scales are shown in Fig. 2.