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Tea Flushes Identification Based on Machine Vision for High-quality Tea at Harvest

Xiaojun Jin[1,a], Yong Chen[1,b], Yingqing Guo[1,c], Yanxia Sun[1,d] and Jun Chen[2,e]

[1]College of Mechanical and Electronic Engineering, Nanjing Forestry University, P. R. China

[2]School of Instrument Science and Opto-electronics Engineering, HeFei University of Technology, P. R. China

[a]chironking@gmail.com, [b]chenyongjsnj@yahoo.com, [c]gyingqing@126.com, [d]sunyanxia@hotmail.com, [e]zdmscj@sina.cn

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Abstract. Tea flushes identification from their natural background is the first key step for the intelligent tea-picking robot. This paper focuses on the algorithms of identifying the tea flushes based on color image analysis. A tea flushes identification system was developed as a means of guidance for a robotic manipulator in the picking of high-quality tea. Firstly, several color indices, including y-c, y-m, (y-c)/(y+c) and (y-m)/(y+m) in CMY color space, S channel in HSI color space, and U channel in YUV color space, were studied and tested. These color indices enhanced and highlighted the tea flushes against their background. Afterwards, grey level image was transformed into binary image using Otsu method and then area filter was employed to eliminate small noise regions. The algorithm and identification system has been tested extensively and proven to be well adapted to the complexity of a natural environment. Experiments show that these indices were particularly effective for tea flushes identification and could be used for future tea-picking robot development.

Introduction

As one of the three drinking, tea is popular all over the world. Tea trees are mainly planted in Asia, including China, Japan, India, etc. For many years, traditional manual tea picking has been a hard job during tea harvest season. Recent developed tea harvesting machine works in mechanical shearing mode (non-selective picking, old leaves were usually picked together with the flushes and there will be more broken leaves and partial flushes.), and does not meet the demand for harvesting and producing high-quality tea, which only consists of the terminal bud and the second even third leaves (these bud and leaves are called flushes). With the labor cost substantially increased, the development of an intelligent tea-picking robot for high-quality tea has great commercial and social significance. Identification of the tea flushes from their natural background is one of the most challenging tasks.

Color indices were employed in many studies to distinguish plant material from the background [1-4]. Woebbecke et al. [5] evaluated some color indices to distinguish weeds from the soil and residues. The normalized excess green index (ExG = 2g-r-b) and modified hue were found to be the most efficient in identifying the weeds. Meyer and Neto [6] proposed an improved vegetation index, which was defined as Excess Green minus Excess Red (ExG-ExR), to separate the weeds from the soil and residue background.

So far, little work has been done on recognizing the tea flushes from their natural background (including old leaves, stems, soil, etc.). The long-term objective of this study is to develop a tea-picking robot that can automatically pick tea flushes with great efficiency in order to manufacture high-quality tea. This paper will propose several color indices and image processing algorithms to identify tea flushes for future automatic picking.

Materials and Methods

A set of color images of Longjing tea, which is amongst the finest and most representative of green teas in China, were acquired after germination with a DaHeng camera(HV1300FC, DaHeng Image, Inc., Beijing, China) in Longjing tea plantation (Hangzhou, China) under natural sunlight. Processing software was developed using Visual Studio 2010 (Microsoft Co., LTD., Redmond, WA, USA).

The proposed method. High quality tea comes from the flushes, which ensures that only the best leaves of the tea plant are collected and manufactured for producing the tea. The color of the old leaves is dark green, while the flushes usually have a light color, which appears greenish-yellow (Fig. 1). In order to highlight the tea flushes against their background, a variety of color indices on the CMY, HSI, and YUV values were carried out. These indices are shown in table 1.

Table 1 Color indices used in tea flushes recognition.

Color space	Type	Color indices
CMY	Color difference	y-c
		y-m
	Ratio index	(y-c)/(y+c)
		(y-m)/(y+m)
HSI	Channel	S
YUV	Channel	U


(a)

(b)

Fig. 1 Original Longjing tea images. **(a)** field image captured in the afternoon. **(b)** field image captured in the morning.

Color indices in CMY color space. The CMY color model is a subtractive color model, which consists of cyan, magenta, and yellow. It is the complement of the RGB color space since cyan, magenta, and yellow are the complements of red, green, and blue respectively.

Similar to RGB color model, the gray levels of the C (cyan), M (magenta), and Y (yellow) components are sensitive to the intensity of the light source as well as the viewing and illumination angles [7]. Therefore, it is necessary to normalize the CMY coordinates to reduce the sensitivity to illumination.

Color difference (C_{ym}, C_{yc}) and Ratio index (R_{Iym}, RI_{yc}) were proposed to identify tea flushes versus background, which were defined as follows:

$$C_{ym} = y - m, C_{yc} = y - c, RI_{ym} = \frac{y-m}{y+m}, RI_{yc} = \frac{y-c}{y+c} \tag{1}$$

$$c = \frac{C}{C+M+Y}, m = \frac{M}{C+M+Y}, y = \frac{Y}{C+M+Y} \tag{2}$$

where c, m and y are the normalized CMY coordinates ranging from 0 to 1.

Color Channels in HSI and YUV Color Space. HSI is a cylindrical-coordinate representation of points in an RGB color model, which stands for hue, saturation, and intensity. In YUV color model, Y represents luminance, U and V components represent color information. After intensive studies, we found that HSI and YUV models were useful for image segmentation.

Image processing. The grey level image was then transformed into a binary image using Otsu method [8]. Then, an area filter using the thresholding technique was employed to eliminate small noise regions in the binary image.

Results and Discussion

A program was developed to implement the identification algorithm. Figure 2 and 3 represent the results when the indices were applied to the Figure 1(a), which was captured in the field tea plantation in the afternoon under natural daylight conditions.

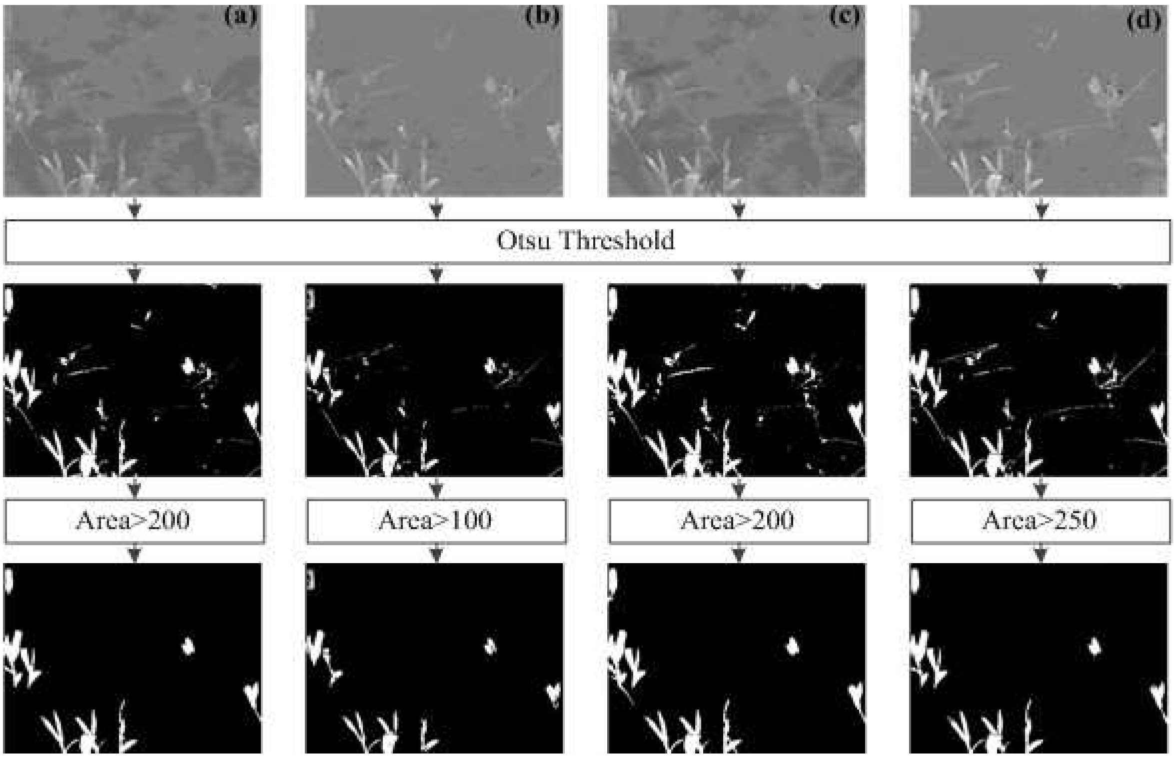

Fig. 2 Flushes identification based on indices in CMY color space. **(a)** C_{yc} **(b)** C_{ym} **(c)** RI_{yc} **(d)** RI_{ym}

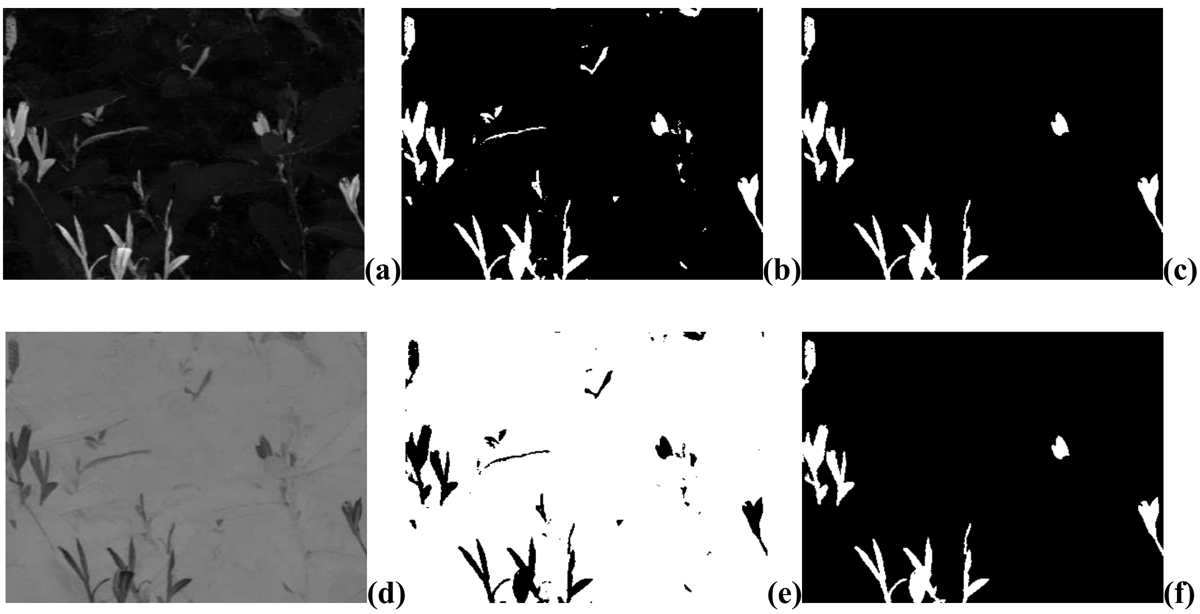

Fig. 3 Example of flushes recognition in HSI and YUV model. (a) S component. (b) binary image created with the Otsu's method. (c) image after area filter. (d) U component. (e) binary image created with the Otsu's method. (f) image after area filter.

It is observed that the background had a lower gray-level than the flushes in C_{ym}, C_{yc}, RI_{ym}, RI_{yc} indices as well as in S channel, while the flushes look darker in U channel. Background segments have uniform intensity. Hence, it is feasible to separate the tea flushes from the background using these color indices.

The grey level image was transformed into binary image. The best performance was achieved using the method of Otsu, which is based on an analysis of the histogram resulting from the gray level image calculation.

An area filter was employed to eliminate small noise regions in the binary image. The area of each regions were calculated. Objects smaller than a preset threshold (derived through trial and error) were considered as noise and filtered. Objects larger than the threshold were considered as flushes. Example results show that the area filter was successful in eliminating misclassified pixels (noises).

Fig. 4 Example results of image processing when the proposed indices were applied to the Figure 1(b), which was captured in the morning. **(a)** C_{yc} **(b)** C_{ym} **(c)** RI_{yc} **(d)** RI_{ym} **(e)** S channel. **(f)** U channel.

Example image processing results of Figure 1(b), which was captured in the field tea plantation in the morning under natural daylight conditions, are given in figure 4. Examination of figure 4 indicated that background was completely removed from the image when indices were applied. Additionally, it is evident that the proposed indices and identification algorithm are able to automatically adapt to the various lighting conditions, which render them suitable to work under natural conditions for intelligent robotic tea picking.

The indices Cym, Cyc, RIyc and RIym run at about 0.0280s, 0.0275s, 0.0317s and 0.0299s respectively, while they run at about 0.0564s, 0.040s when channels S and U were applied. Therefore, color indices in CMY color space gave effective classification performance with a lower computational cost compared to the indices in HSI and YUV color spaces.

Conclusions

In this study, an image processing algorithm to automatically identify the tea flushes for a machine vision system that guides a tea-picking robot were successfully developed. Color features were analyzed to distinguish the flushes from their natural background. Several color indices including y-c, y-m, (y-c)/(y+c) and (y-m)/(y+m) in the CMY color space and channels in HSI and YUV color models were studied and tested.

Further studies showed that the y-c, y-m, (y-c)/(y+c) and (y-m)/(y+m) indices in CMY color space and S, U components in HSI and YUV color models were particularly effective for tea flushes recognition. Results also indicated that the presented algorithm was able to eliminate the influences of light intensity, and that it could be used under outdoor sunlight conditions and with natural backgrounds. The proposed indices and segmentation algorithm are key steps for developing an intelligent tea-picking robot.

Future work will concentrate on the development of robust and high-performance algorithms to determine the 3-D location of flushes. Other technologies such as stereo vision would somehow enter into the algorithm to obtain the depth information.

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