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Original research article

A robust fruit image segmentation algorithm against varying illumination for vision system of fruit harvesting robot

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ABSTRACT

Vision system is the crucial component of fruit harvesting robot for recognising fruit, however, which is seriously affected by varying illumination when the robot works in real natural environment. A robust fruit segmentation algorithm against varying illumination for vision system was proposed with the aim of effectively extracting fruit object in the natural environment. The method involved the application of improved wavelet transform to fruit image to normalise illumination of object surface. Then Retinex-based image enhancement algorithm was used to highlight fruit object of illumination normalised image. Finally fruit image was segmented by implementing *K*-means clustering. Three kinds of fruit images of different colour under sunny and cloudy days were segment using the proposed method respectively and the experimental results showed that the proposed algorithm could be robust against the influence of varying illumination and precisely segment different colour fruits.

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1. Introduction

Manual fruit harvesting is a time-consuming and high labour-costs job, which urges that many fruit harvesting robots have been developed [1–4]. A typical fruit harvesting robot consists of a manipulator, an end-effector, a mobile device, a vision system and a control system, in which vision system plays a vital role in producing images for the robot to recognise fruit. Normally, shape based analysis and colour based analysis are used for the vision system to segment fruit image [5]. Circular Hough transform algorithm based on fruit shape information was applied in segmenting fruit image, however, the interference of background, leaves, or curvature contributed to low fruit detection rate [6,7]. The method of threshold segmentation or colour indices was considered as a common method of fruit image segmentation based on colour analysis. The fruit object was extracted by adjusting spectral distribution or setting up colour index [8–12]. But due to uneven illumination on the surface of objects causing by varying light, light spots or shadows can easily form on the surface of fruit and other objects, which causes serious errors in segmentation based on colour analysis.

In this paper, a robust fruit image segmentation algorithm against varying illumination for vision system of fruit harvesting robot was proposed. The fruit colour image was obtained in real natural environment, surface illumination of which was

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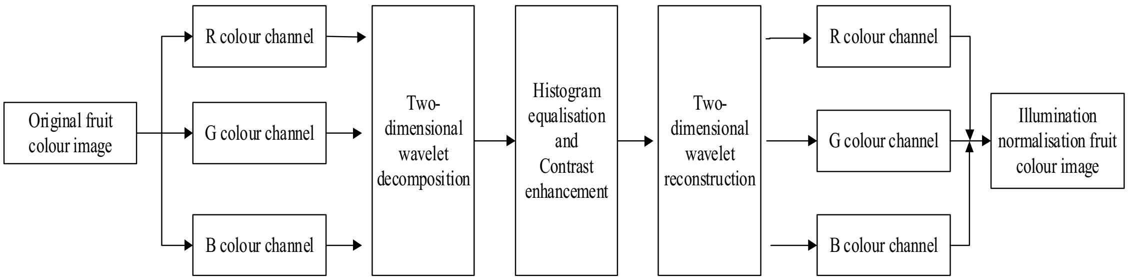

Fig. 1. Flow chart of improved wavelet-based fruit colour image illumination normalisation.

normalised using an improved wavelet transform. And then Retinex algorithm was used to highlight fruit object. Fruit was finally segmented by implementing *K*-means clustering. Three kinds of fruit images of different colour under sunny and cloudy days were used to test the performance of the proposed algorithm.

2. Materials and methods

2.1. Image acquisition

In order to evaluate the effect of the proposed fruit image segmentation algorithm, 300 fruit images under outdoor conditions captured in three orchards were tested. The image acquisition conditions were as follows: grape, 100 images in a grape orchard in Tianjin; dates, July 21, 2014 to July 25, 2014; litchi, 100 images in a litchi orchard in Guangzhou; dates, June 20, 2015 to June 25, 2015; citrus, 100 images in a citrus orchard in Hengyang; dates, October 10, 2015 to October 15, 2015; weather, cloudy and sunny. The images were captured by a CCD colour camera (model MV-VD120SC) which had a digital video output of 1280 by 960 effective pixels, and were stored in a PC with 4 GB RAM, an Intel Core i5-2500 CPU, a Windows 7 operating system. The images were processed using both the proposed segmentation algorithm under Matlab 8.3 programming environment and image editing software Photoshop 13.0 by manually labelling fruits for artificial criteria. The artificial criteria used from the method of the reference [5] was stated: the remaining fruit portion in the difference image between the manual segmentation image and the image segmented by the proposed algorithm was labelled manually, and the pixels were calculated. If the pixel rate of the remaining portion to that manually labelled was less than 0.05, then the fruit segmented by the proposed algorithm could be considered as successful and its segmentation rate could be calculated.

2.2. Improved wavelet-based illumination normalization

Varying illumination mainly affects the low-frequency components of fruit colour image by changing brightness and contrast of image [5]. Due to ability of combining space domain and frequency domain to analyze, wavelet is a potential tool for extraction details and other approximate composition of image.

As shown in Fig. 1, original fruit colour image was firstly decomposed into R, G, B three colour channels in RGB colour space. These colour channels were two-dimensional gray scale images. Using formula 1, which was the two-dimensional discrete wavelet transform (two-dimensional Mallat algorithm) in the first layer, three colour channels were decomposed into low-frequency component and high-frequency component respectively. Then, in this paper, the low-frequency component and the high-frequency component were processed using histogram equalisation and contrast enhancement respectively. The processed low-frequency component and high-frequency component were reorgnised into three different colour channels using two-dimensional wavelet reconstruction using formula 2 respectively. Finally, improved wavelet-based illumination normalisation was accomplished by reorganisation of the three illumination normalised colour channels of the fruit colour image.

$$\begin{cases} d_{j+1}^{V}(x,y)=\sum_{k}\sum_{l}g(k-2x)h(l-2y)c_j(k,l) \\ d_{j+1}^{H}(x,y)=\sum_{k}\sum_{l}g(k-2x)h(l-2y)c_j(k,l) \\ d_{j+1}^{D}(x,y)=\sum_{k}\sum_{l}g(k-2x)h(l-2y)c_j(k,l) \\ c_{j+1}(x,y)=\sum_{k}\sum_{l}g(k-2x)h(l-2y)c_j(k,l) \end{cases} \quad (1)$$

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