Adhesive sweet pepper fruits segmentation method based on AHE and normalized cut

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Abstract: As for vegetables in China, sweet pepper is the second-widest planted next only to Chinese cabbage and exported a lot to Japan, Southeast Asia and other countries. The visual recognition system of fruits is a necessary part in sweet pepper harvesting robot. In the meantime, the segmentation of adhesive pepper fruits is also inevitable in the quantitative analysis of the severity of sweet pepper diseases. However, few studies had research on this problem. So in order to get well recognition and segmentation for adhesive sweet pepper fruits in natural conditions, a method is proposed that combines adaptive histogram equalization (AHE) method and normalized cut (Ncut) method. Firstly, original image in RGB color space is processed by R channel subtracting G channel and then using mathematical morphological operation to segment the images to get close-up adhesive sweet pepper fruits and remove the tiny noise parts. Then use AHE algorithm to enhance the local details in the fruit surface, especially the edges of the adhesive part. Finally, based on the reinforced image, edges on the overlapped area are extracted from the image through the Ncut method. To prove its validity of this method, 19 adhesive sweet pepper fruits images under natural environment have been tested. Experiment result shows that, for adhesive sweet peppers in normal natural conditions, the mean segmentation error of this method is 5.4%. The mean contact ratio between segmented fruit image and original fruit image is 93.91%. Furthermore, our method maximized the utilization of the original contour information to build the new edge. The results demonstrate that out method has certain reference significance to detection of sweet pepper fruits and segmentation of other fruits of irregular shape under natural conditions.

Keywords: image segmentation, normalized cut, sweet pepper recognition, overlapped objects segmentation, graph theory, boundary segmentation

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1 Introduction

China is a great nation in term of vegetable cultivation. Quantity and per capita availability both rank first in the world. Planting area of sweet pepper is second-widest next only to Chinese cabbage in China and the fruits are exported a lot to Japan, Southeast Asia and many other countries. Harvesting robot technology is an integral part of modernization of agriculture. Therefore, it's strongly necessary to study the automatically harvesting robot of sweet peppers.

As to the visual system of harvesting robot, accurate detection and segmentation of the close-up fruit is the key to fruit picking successfully. However, it's quite common that sweet peppers are adhesive or overlapped with each other and the fruit is usually sheltered from other noises such as stems and leaves in nature environment . The shape of the sweet pepper fruit is irregular which means cannot be fitted with circle, ellipse or square. And more of these, the surface of the fruits has gully lines which means the surface is not flat or convex like surface of apple and citrus. Hence acquisition and segmentation of accurate sweet pepper fruits target in natural conditions are difficult points in development of the sweet pepper harvesting robot.

Harvesting robot have obtained some achievements in crops such as apple, kiwi fruit, cucumber and tomato, studies on sweet pepper are not so much yet. It the

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meantime, segmentation in image of adhesive crops have made some progress. A method of a sliding comparison window local segmentation algorithm is proposed, it can segment various type of surface defects (Rong and Rao, 2017). Using principal component analysis, three color channels are selected from the R, G, B, H, S, and V channels, then an adaptive channel selection Chan-Vese algorithm is proposed, reducing the number of iterations (Hu et al., 2017). The fusion of K-means and Ncut algorithm can solve the problem of accurate segmentation of the overlapped mature apples, which is proved to be better than Hough algorithm in the same condition (Wang, 2016). Many fruits have the shape like a circle or a ellipse so there are many researchers tried to segment the fruits by fitting the edge with a circle or ellipse. The edge of the fruit was get first, then circle is used to fit the edge of apple to separate the adhesive fruits, the center of the single apple is determined by applying max-min distance method on overlapped apples, after that the radius is equal to the minimum distances of every single pixel on the edge to the center of the contour. Finally, the overlapped apples would be separated by fitting circle on the image with the calculated center and radius (Shen, 2016). Snake model can used to segment the fruit from the background and with corner detection method, the corner in the edge would be detected therefore to locate the overlapped place in apples (Xu and Li, 2015). In grape harvesting, the color of grape stem is complex and contour is irregular rising the difficulty to locate the picking position. To locate the picking position, a new method is raised which combined the cluster image segmentation and minimum distance constraint algorithm. The new method solved this problem successfully (Luo et al., 2015). A method which combined the K-means and convex theory algorithm is posed to separate the overlapped apples, which reduced the complexity and improved the effectiveness (Song et al., 2015). Fast normalized cross correlation can improve the recognition efficiency when applying to the overlapped apples for pattern matching (Zhao et al., 2015). There's another way to improve the performance in segmentation in overlapped fruit, using binocular stereo vision system to get anaglyph which extend two-dimensional image to three-dimensional space, the edge error was restrained to 5.47%, that's pretty good effect (Peng et al., 2012). Because of the kiwi fruit's physical property, Hough transformation is applied to fit the fruits as ellipse in natural condition to get the adhesive fruits separated (Cui et al., 2012). A fusion algorithm of adaptive PCNN and maximum entropy approach gets pretty good result in image segmentation (Zhang Xinwei and Yi Kechuan., 2015). The length-width ratio is another concerned feature in overlapped crops. Using pose information of adhesive grains skeletal adhesion point improved the performance of grains segmentation. This method was proved to have better adaptability in complex serious adhesive grains (Niu et al., 2014). Boundary curvature estimation is applied to pick up the pits which mean catastrophe points, then with these feature points, the fruits would be fitted. Because of the characteristics of intensity inhomogeneity, noise, and blurred edges in crop lesion color images, an improved CV model and an efficient termination criterion in level-set for wheat leaf lesion segmentation is proposed, and get pretty good result (Hu et al., 2017). In natural condition, fruit detection and segmentation are not easy because of the uneven lightness distribution, the leaves blocking, stem division and much more other noises. By a sliding comparison window, local segmentation algorithm can successfully segment various types of surface disease and not affected by other noises (Rong and Rao et al., 2017). The pseudo canny edges can be divided into three categories and in this way different texture features can be constructed, this is a remarkably effective segmentation algorithm. In addition, segmentation algorithms for protein and cells adhesion have reference value to crops adhesion. Harris corner detection and polygon fitted were applied to get concave corners on the adhesion protein, then separation lines were constructed by concave points match to divide single protein (Zhao et al., 2017). Another method to segment overlapped protein is fusion of bottleneck detection and Dijkstra algorithm, this way can only divide one part into two parts, multicellular division needs to be determined and segmented repeatedly. Cells outlines can be distributed into two classes, strong outline and weak outline. Annular

dynamic contour search algorithm was applied to locate the weak outline so as to divide the overlapped cells.

Above all, few researchers study on sweet peppers in image segmentation, it's difficult to segment the adhesive sweet pepper fruits because the shape of the fruit is irregular, the surface is uneven and easy to be disturbed by illumination. Most methods applied on apple, citrus are not really suitable for sweet peppers, such as Hough transformation, least square method and so on. The intensity variation on the edge is not prominent because of the gully lines and shadows on the surface, further increasing the difficulty of detection and segmentation on adhesive sweet pepper fruits. This article raised a new method to solve these problems well, this method combined adaptive histogram equalization method and normalize cut method to segment adhesive sweet peppers in natural conditions. Firstly, image sample of RGB color space is calculated by R channel subtracting G channel and then segment to get close-up adhesive sweet pepper fruits by mathematical morphological operation and remove the tiny noise parts. Then, use AHE algorithm to enhance the details in the fruit especially the intensity variation of edge in the adhesive part. Finally, based on the reinforced image, edge on the overlapping area extracted from the fruit through the Ncut method, the foreground fruit is segmented completely.

2 Materials and method

2.1 Detailed enhancement on sweet pepper fruits

This article adopts methods including R channel subtracting G channel to get the initial fruit segmented image. Mathematical morphological operation, void filling, denoising and such steps to get the basic fruit image. The process is shown in Figure 1.

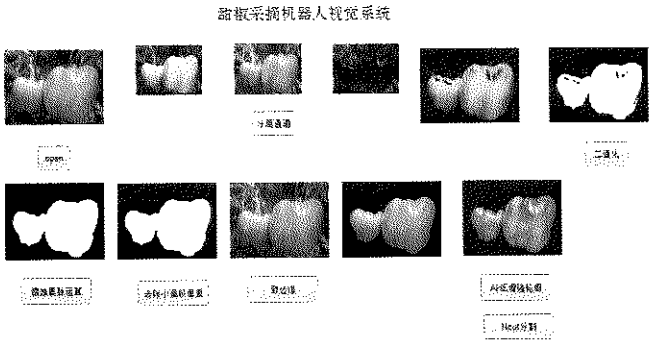


Figure 1 The initial extraction system interface of sweet peppers

As is shown in Figure 2, the fruits are still in adhesion at this point.

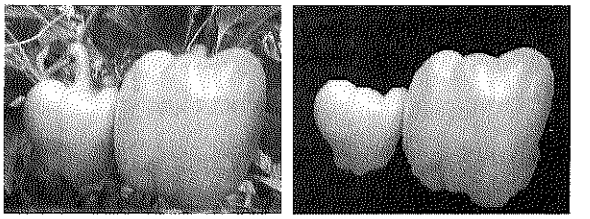


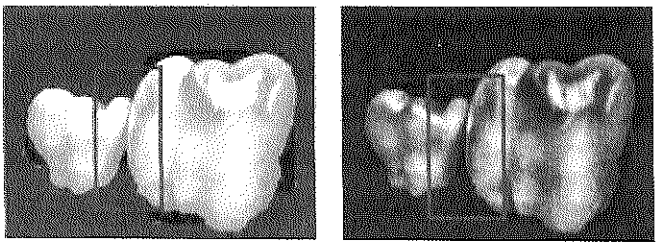
Figure 2 The initial extraction effect of sweet peppers

2.1.1 Introduction to adaptive histogram equalization algorithm

Histogram equalization algorithm is available to enhance the contrast of image, it can be divided into direct contrast enhancement and indirect contrast enhancement. Histogram equalization algorithm is to stretch the gradation histogram in the original image from a relatively intensive gray space to the whole gray scope, so to get a detail enhanced image. However, conventional histogram equalization algorithm have shortcoming in some situation, when there is too bright or too dark region in the original image, conventional histogram wouldn't play an effective role and would even cause distortion in these conditions. Furthermore, conventional histogram equalization has some other flaws such as it may cause gray scale decrease, detail lost after the transformation and image distortion influenced by noisy points.

Adaptive histogram equalization (AHE) is a computer image processing method to promote the image contrast. Different from the conventional histogram equalization algorithm, AHE adopts local processing method to equalize the histogram, which means by calculating the histogram in a local window, AHE redistributes the gray level to enhance the image to get more distinct details in a local window, in this way, the new image wouldn't be influenced by regions of no interest. The main idea of this algorithm is to equalize the histogram of a pixel and a small rectangular area around this pixel, the way redefining the gray value of a pixel is same with conventional histogram equalization method.

The global histogram equalization effect is shown in Figure 3a, while the effect of adaptive histogram equalization is shown in Figure 3b. As demonstrated in the figure, the edge contrast in Figure 3b is much more obvious than in Figure 3a.



a b

Figure 3 Effects of different histogram equalization methods

The Equation of local region contrast enhancement is shown as follows:

$$\hat{x}_{i,j} = m_{i,j} + k(x_{i,j} - m_{i,j}) \tag{1}$$

The parameters $x_{i,j}$ and $\hat{x}_{i,j}$ respectively represent the gray value before transformation and after. And $m_{i,j}$ is the average gray value in the rectangular frame.

2.2 Segmentation in adhesive sweet pepper fruits

2.2.1 Introduction to normalized cut algorithm

Normalized cut (Ncut) algorithm is used to segment adhesive fruits after getting the detail enhanced image.

Ncut algorithm is proposed by Sin in 2000, it's a global optimization method based on graph theory. Technology based on graph theory has always been a hot topic. Graph theory describes a image as a weighted undirected graph, regarding the pixels as nodes in the graph, the relevance between the pixels as edges. Object segmentation is carried out in the rule of nodes clustering, in this way, conventional image segmentation problem is converted into an optimization problem in graph theory.

The Equation of Ncut is shown as the following:

$$Ncut(A,B) = \frac{cut(A,B)}{assoc(A,V)} + \frac{cut(A,B)}{assoc(B,V)} \tag{2}$$

$$assoc(A,V) = \sum_{u \in A, t \in V} w(u,v) \tag{3}$$

The result value of the Equation (2) is between-class similarity, the lower the between-class similarity is, the better the segmentation result. Equation (3) is to calculate the sum of weight between Part A and the whole graph nodes V.

$$Nassoc(A,B) = \frac{assoc(A,A)}{assoc(A,V)} + \frac{assoc(B,B)}{assoc(B,V)} \tag{4}$$

Within-class similarity is solved in Equation (4), the higher the within-class similarity is, the better the result.

The Equation can also be written as:

$$\begin{aligned} Ncut(A,B) &= \frac{cut(A,B)}{assoc(A,V)} + \frac{cut(A,B)}{assoc(B,V)} \\ &= \frac{assoc(A,V) - assoc(A,A)}{assoc(A,V)} + \frac{assoc(B,V) - assoc(B,B)}{assoc(B,V)} \\ &= 2 - \left(\frac{assoc(A,A)}{assoc(A,V)} + \frac{assoc(B,B)}{assoc(B,V)}\right) \\ &= 2 - Nassoc(A,B) \end{aligned} \tag{5}$$

It can be seen that Ncut algorithm not only ensure the lowest inter class similarity, in the meantime, it guarantees highest between class similarity, so the effect of Ncut is global optimized in pixel perspective.

The algorithm is calculated as following:

First, according to the graph theory, transform the original graph into an undirected weighted graph $G = (V, E)$, then calculate the weight matrix W and D.

Second, based on feature system Equation $(D-W)y = \lambda Dy$, determine the feature values and corresponding feature vectors.

Finally, cluster the feature vectors using cluster algorithm.

As shown in figure 4 is the contour result extracted by Ncut algorithm from the enhanced image. The goal of Ncut is to cluster the pixels in order to get global optimized result with lowest within-class similarity and highest between-class similarity. The contour on the adhesive part is recognized successfully, showing that Ncut have a nice effect in recognizing the edge on overlapped or adhesive parts.

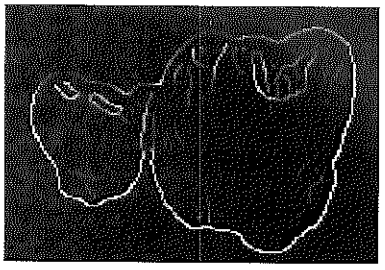
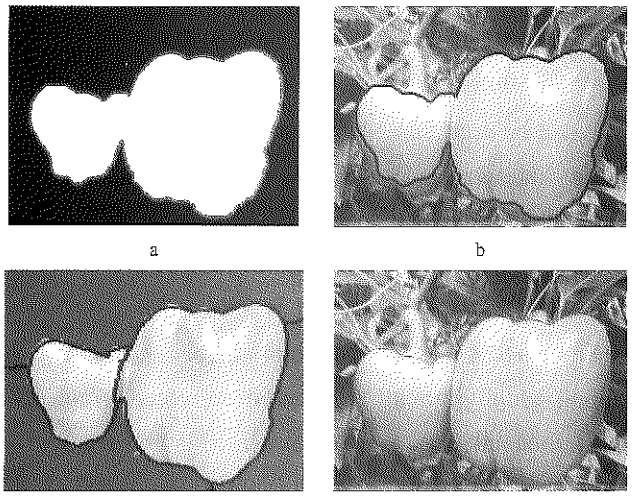


Figure 4 Effect on edge of the adhesive fruits using Ncut method

The following figure shows the segment result under our method. Figures 5a and 5b is the result using sobel operator on adhesive sweet pepper fruits image to detect the edge directly without Ncut algorithm. Figures 5c and 5d are the result using Ncut algorithm. It can be observed that our method not only divides off the adhesive sweet peppers, but also keeps the original edge basically. There are many researchers using Hough transformation to fit apples, citrus, kiwi fruits with circles and ellipses to

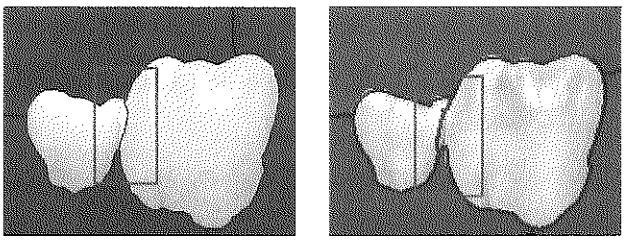
divide the overlapped and adhesive fruits, but the flaw in this way is obvious, irregular shape cannot be fitted with regular form, and the fitted shape didn't use the original image edge information comprehensively.



a b c d

Figure 5 Final effect on edge of the adhesive fruits using Ncut method

Figure 6 shows the experiment results. The result without AHE algorithm in Figure 6a have more deviation than result with AHE algorithm in Figure 6b, indicating the effectiveness of AHE method and dedicating that AHE algorithm having certain significance to other detail enhancement study.



a b

Figure 6 Effect of AHE method on segmentation

3 Results and discussion

Nineteen samples were tested in this paper, the segmentation results are shown in the following table.

Table 1 Segmentation results with our method and reasons

Sample number	Real area in image (pixel)	Segmented area with our method (pixel)	Overlapped ratio (percent)	reason	Error segmentation ratio (percent)
1	16036	13931	86.33		
2	41844	42847	100.00		1.4
3	13880	10225	73.66	Stem and leaf block	
4	9562	9613	99.12		
5	20657	18952	91.72		
6	2106	2034	96.65		
7	2654	2700	97.91		
8	3762	4577	82.10	Overlapped widespread	
9	28102	27596	98.11		
10	39125	38988	99.64		
11	6013	5676	94.39		
12	9026	8923	98.85		
13	10852	11365	95.49	Large scale shaded surface	
14	9302	9288	99.84		
15	28330	27765	98.01		8.6
16	9704	8303	85.56	Large scale shaded surface	
17	24732	23484	94.95		
18	9056	9003	99.41		
19	7326	7336	99.86	Blurred edge	

Note: Error segmentation means the ratio of error segmentation part from background to the complete real fruit part.

4 Conclusion

Compared with other crops like apple, tomato, citrus and kiwi fruit, sweet pepper fruit is more difficult to detect and segment from the image because of the irregular shape and uneven textured surface, so the studies on detection and segmentation of sweet pepper fruit in method of computer visual are few. Segmentation of adhesive multiple sweet pepper fruits has become one of the research key points and difficulties in sweet pepper

harvesting robot. This paper proposes a fusion method of AHE and Ncut method to segment the overlapped sweet pepper fruits, some progress has been made in automatic detection and segmentation of adhesive sweet pepper fruits in natural environment. Experimental results show that:

1) The uneven surface and illumination leads to partial shading in sweet pepper fruits, so the contour on the adhesive part is easy to be confounded with the fruit itself. To get a better detection of gray scale variation through Ncut method, this paper adopts AHE algorithm to enhance the details in the fruit surface especially to enhance the edge on the adhesive region. Compared with the result in conventional histogram equalization algorithm combining with Ncut, our method gets a better result which is more close to the actual situation, showing our method have certain significance in segmenting overlapped irregular objects in natural complex conditions.

2) The shape of sweet pepper fruit is irregular, so it's inefficient to use corner detection method and concave points match method in dividing the adhesive peppers. Ncut method, which is based on graph theory of global optimization, can segment the adhesive fruits on the basis of the original outline. It can be concluded that Ncut is feasible, supplying some ideas to further study on segmentation of multiple adhesive fruits of irregular shapes.

Algorithm in this paper basically solves the problem of segmentation of multiple adhesive sweet pepper fruits in natural condition. However, in natural environment, there are situations that multiple fruits overlap seriously. In these situations, our method is not very effective and needs to optimize from the perspective of detail enhancement. The fruit involved in our paper is mainly yellow peppers and red peppers, not including green peppers yet. How to enlarge generalization of this method still need further study.

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