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GREENHOUSE TOMATO FRUIT RECOGNITION AND TWO-DIMENSIONAL INFORMATION ACQUISITION OF FRUIT AXIS

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ABSTRACT Existing tomato picking robots have low accuracy of target fruit recognition due to factors such as natural light intensity changes and excessive occlusion. The clustered tomato growing in the greenhouse is selected as the research object, and a method to identify the axis of each single fruit for a clustered tomato. Based on the tomato image collected on-site as the data source, the I color component in the YIQ color space is selected as the image segmentation factor first. Then the automatic threshold segmentation of the image is completed based on the iterative method, and then the morphological operation and Hough transform is used to identify the tomato fruit. Finally, based on the moment feature, the characterization and identification of the fruit axis is completed in the image, and the comparison with the marked area of actual fruit axis in the image is carried out. The comparison results show that the accuracy of tomato fruit recognition based on morphological operation and Hough transform is 93.2%, and the accuracy of fruit axis recognition is 85.5%, which meets the accuracy requirements of robotic picking.

Keywords: Tomato,Pick,Image Processing, Hough Transform, Fruit axis.

INTRODUCTION

China has a vast agricultural planting area and is one of the countries with the largest tomato planting area and production in the world(Ji, Zhang, Yuan, & Li, 2014). At present, the methods of picking tomatoes in domestic greenhouses are mainly manual, and manual picking methods have the problems of low efficiency and high cost, and the high temperature and high humidity environment of the greenhouse is also a challenge to the physical strength of the workers. In addition, in recent years, with a large number of migrant workers in our country entering cities to work and the increasingly serious problem of population aging, it has become increasingly difficult to harvest tomatoes.

Many scholars have done a lot of research on the development of machine vision systems for image acquisition, fruit and vegetable detection and positioning (Gongal, Amatya, Kark Ee , Zhang, & Lewis, 2015). Slaughterl et al. used color cameras to acquire images and detect oranges based on the hue, saturation, intensity (HSI) color components of the object's "HS" color space and RGB color space, with a classification accuracy of 75%(Slaughter & Harrell, 1989).Hamuda et al. proposed a new algorithm based on color features and dilation and corrosion,the sensitivity is 98.91%, and the precision is 99.04%(Hamuda, Ginley, Glavin, & Jones, 2017). Arivazhagan et al. In order to automatically detect the status of leaf diseases and insect pests, extract texture features to calculate the useful parts of leaves, and classify them through classifiers. The proposed algorithm can successfully detect and classify the detected diseases with an accuracy rate of 94%(Arivazhagan, Shebiah, Ananthi, & Varthini, 2013). Tao et al. proposed an improved three-dimensional descriptor color-fpfh that combines color features and three-dimensional geometric features to distinguish apples, branches and leaves. The experimental results show that the accuracy rate is as high as 73.46%(Tao & Zhou, 2017). In the image processing stage of acquiring the location information of the target fruit, the most difficult thing to overcome is the influence of three factors on the target fruit recognition, which are the mutual occlusion between tomato fruits, the occlusion between branches and fruits, and the changing natural light.

The clustered tomato growing in the greenhouse is selected as the research object, and a method to identify the axis of each single fruit for a clustered tomato.

MATERIALS AND METHODS

Data acquisition

As shown in Figure 1(a), a day with clear weather and sufficient light was selected and 84 tomato images were collected in a greenhouse with a shooting distance of 650mm and a shooting height of 580mm. The collection site was the Yangdu Base in Haining, Jiaxing, Zhejiang Province, China. The acquisition device is a binocular camera, the model is HNY-CV-002, the shooting frame rate can reach 30 frames/s, and the image size is 2560*720, as shown in Figure 1(b). A simple, efficient, and fast computing software system is very important for all stages of image processing. This article uses MATLAB image processing module and OpenCV3.0 function library as the main image processing tools, and the software development platform is Windows 10.In order to adapt the research method to the changing natural environment, the pictures taken include complex backgrounds, uneven light intensity, adhesion between fruits, occlusions, and the same bunch of fruits containing tomatoes with different degrees of maturity, as shown in Figure 2 shown. According to international standards, ripe tomatoes are those fruits that have a red color of more than 90%. Other tomatoes are considered immature. In order to facilitate research, the resolution of the collected tomato pictures is cropped to 640*320, and the cropped pictures are guaranteed to contain at least one or more tomato fruit . After cropping, 74 pictures that meet the requirements are selected for follow-up research.

(a) (b)

Figure 1.(a)Image acquisition of greenhouse, (b)Binocular camera.

(a) (b) (c)

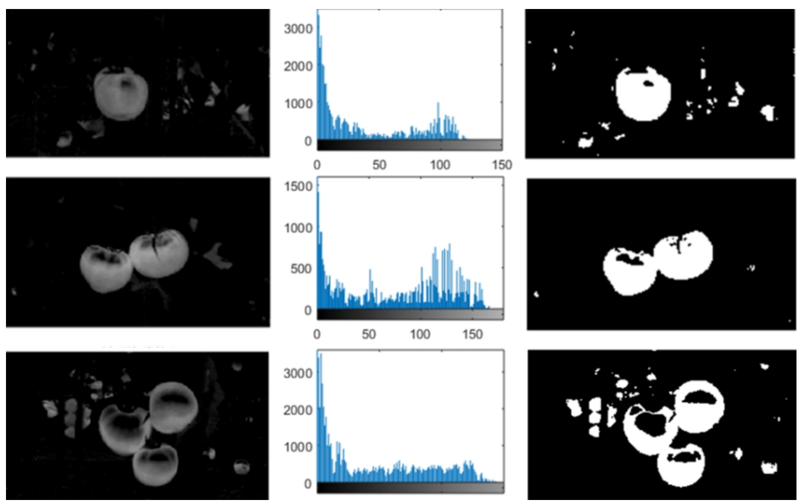
Figure 2. (a)Complex backgrounds, (b)Uneven light intensity, (c)Containing tomatoes with different degrees of maturity.

Tomato image segmentation

As shown in Figure 3(b), obvious double peaks can be obtained on the I color component grayscale image, so this study uses the threshold segmentation method to perform image segmentation. In the collected pictures, due to the influence of the natural environment, the positions of the double peaks between the pictures and the pictures are different, so the fixed threshold is obviously not enough to meet the research requirements. In addition, the collected tomato image is a multi-target image, which also brings new challenges to how to determine an appropriate threshold. There are many existing threshold selection methods, such as Otsu method, maximum entropy method, fuzzy set method, histogram transformation method and feature space clustering method. The traditional segmentation method is to observe the gray histogram of the image and use the bottom value between the two peaks in the histogram as the threshold required for segmentation. Since the selected threshold is a fixed threshold, this method cannot be adapted by dynamic adjustment. For each picture, in contrast, the iterative threshold method can just meet the requirements of this research, and this method can achieve dynamic threshold segmentation.

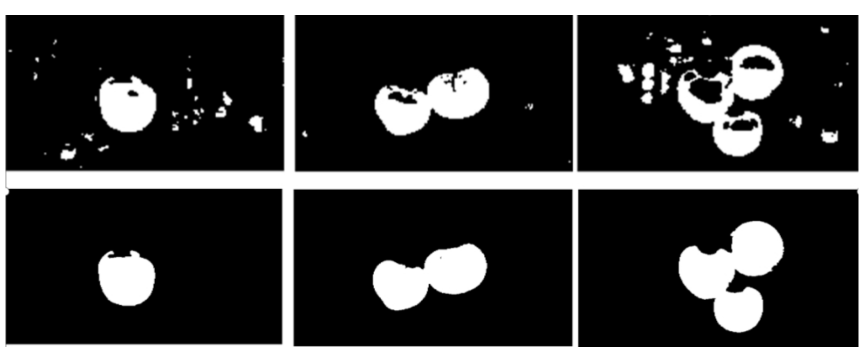
Processing after tomato image segmentation

It can be seen from the segmentation results that although the ripe tomato fruits are successfully extracted from the background, due to the misjudgment of some pixels or other reasons, there are noise points and gaps in the segmented image. The representation in the image is that the white area of interest contains a small black area, as shown in Figure 3(c), which conflicts with the fact that tomato fruits grow continuously and smoothly in reality. Considering that the noise points outside the white area are all areas with a small pixel area, a small area removal method is selected to remove these noise points. For the black area inside the target area, a hole filling algorithm is used to remove it in the research.As shown in Figure 4, it can be seen from the results of the post-processing operation that whether it is an image containing only a single fruit or a tomato bunch with multiple fruits, after small area removal and hole filling operation, the noise points outside the target area and the gap inside can be completely removed.



(a) (b) (c)

Figure3.(a)I color component grayscale image,(b)Gray distribution histogram,(c)Iterative method segmentation results.



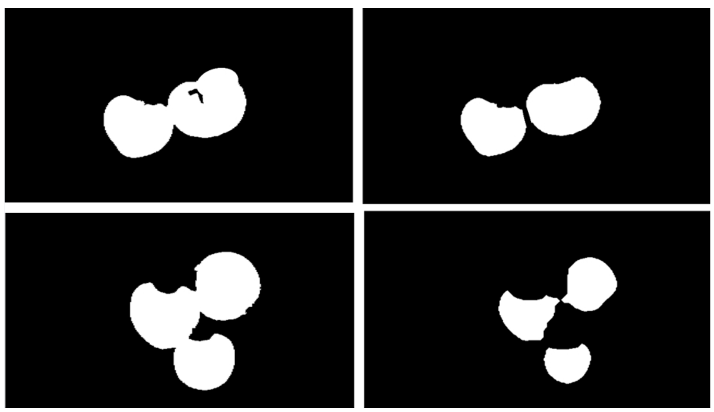
(a) (b)

Figure 4.(a)Single fruit,(b)Many fruits.

Multi-target fruit recognition based on morphological operation and Hough transform

For most greenhouse tomatoes that grow in clusters, due to the mutual adhesion and occlusion between the fruits, the clustered tomatoes mostly present a larger connected area after image segmentation, as shown in Figure 4(b). In order to obtain the posture information of each ripe tomato, the first thing that needs to be completed is the separation of multi-objective fruits. This study completed the separation of multi-objective fruits based on morphological operators and Hough transformation.

Dilation and erosion are the basic operations of mathematical morphology. As shown in Figure 5(b), the fruit has adhesions but less occlusion. After morphological processing is performed on the segmented image, the area of the target area in the image is reduced compared to before processing, but The overall outline has not changed, and the multi-target fruits can be completely separated.



(a) (b)

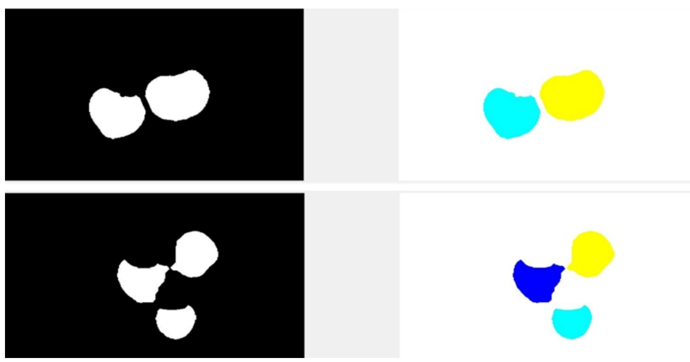
Figure 5.(a)Binarized image,(b)Multi-target fruit separation.

For a single fruit or a bunch of tomatoes with a small number of fruits, the fruit separation method using morphological operations has good results. However, as shown in Figure 6(a), when a bunch of tomatoes contains multiple tomatoes, there are still many connected regions in the target region after noise, hole filling and morphological operation, which leads to the failure of correct separation between fruits.In order to solve this problem, this article uses Hough transform to perform multi-fruit recognition and segmentation operating.Hough transform circle detection operation is carried out on the binary image after morphological operation, and the processing results are shown in Figure 6(c). Compared with morphological operation, this method has significantly improved the recognition effect and accuracy of target fruit, but there is still no way to accurately detect the seriously occluded fruit.

(a) (b) (c)

Figure 6.(a)Tomato skewers containing multiple tomato fruits,(b)Tomato skewers binarized image,(c)Multi-target fruit recognition based on Hough transform.

After the multi-target fruit separation operation is completed, each target area needs to be marked to help the picking robot carry out the work of picking fruits one by one. As shown in Figure 7(b), the separated multi-target fruits are marked with eight neighbor points. The different marked areas have been distinguished by color images, and the background has also changed from black to white.



(a) (b)

Figure 7.(a)Multi-target fruit separatione,(b)Area marking result.

Recognition and characterization of fruit growth posture based on moment feature

In this study, the inertial principal axis of each single tomato area was used to characterize the direction of the fruit axis in the image. Finally, the correctness of the proposed method was further verified by comparing the calculated theoretical fruit axis direction with the marked area of actual fruit axis in the image

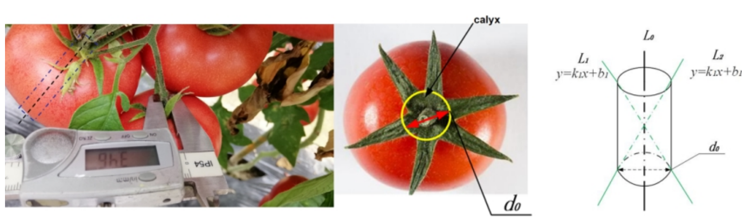
Solve the fruit axis direction of the successfully separated image, as shown in Figure 8(a), use different colors to distinguish the contours of different target areas, and obtain the centroid position and the slope of the fruit axis of each target area, and draw the centerline of the fruit shaft using straight lines of different colors, as shown in Figure 8(b) and (c).

(a) (b) (c)

Figure 8.(a)Obtain the direction of the fruit axis and the position of the center of mass,(b)The position of the centroid and the direction of the fruit axis are solved,(c)Fruit axis drawing.

As shown in Figure 9(a), the diameter of the inscribed circle at the base of the fruit stalk and starfish calyx was measured using a vernier caliper, and the measurement results were mathematically counted, and the average diameter of the fruit stalk was 4.0mm, and the calyx inscribed circle The average diameter is d_0=12mm. As shown in Figure 9(b), the geometric relationship model of the fruit axis is established. The straight line L_0 represents the theoretical fruit axis, and L_1 represents the left limit position of the theoretical fruit axis. At this time, the slope of the fruit axis is k_1, and L_2 represents the left limit position of the theoretical fruit axis, the corresponding fruit axis slope is k_2, there will be many fruit axis solved for different target areas, and it is considered correct only when the corresponding fruit axis is located inside the left and right limit positions the position of the fruit axis of the corresponding fruit is identified.

The method of obtaining the straight line L_0 in the original image is to invite two researchers who are engaged in image processing and have no red-green color blindness. According to the growth characteristics and observation of the tomato fruit, it is artificially expressed through multiple votes, Figure 9(a). The blue rectangular area in is the rectangular cross- section of the cylindrical fruit shaft in space, and the yellow circular area is the largest inscribed circle at the bottom of the starfish-shaped calyx.



(a) (b)

Figure9.(a)Artificial identification of fruit shaft and size measurement of fruit stalk,(b)Fruit axis geometry diagram.

EXPERIMENTAL RESULTS AND ANALYSIS

Based on morphological operation and Hough transform, the fruit separation operation is performed on all image sets. The statistics of separation results are shown in Table 2. Among the 74 collected image sets, there are 48 images containing only a single fruit and 2 ~ 3 mature tomatoes, and the recognition accuracy is 100%. There are 26 images including more than 3 tomato fruit strings, and 21 images are successfully recognized. The recognition accuracy is 80.7%, and the total recognition accuracy is 93.2%.

Table 2 Target fruit recognition results.

Image attributes	Number of images	Correct identification	Error identification	Accuracy
Single fruit	6	6	0	100%
2~3 fruits	42	42	0	100%
More than 3 fruits	26	21	5	80.7%
All images	74	69	5	93.2%

The fruit axis located in the two extreme positions is regarded as the successful recognition situation, as shown in Figure 10. The fruit axis of all the successfully separated target fruits in the previous study are compared with the color images with markings. The successful recognition of the fruit axis is shown on the image, which means that the red line of the theoretical fruit axis is located within the left and right limit positions of the blue rectangular area. When it exceeds this range, it is considered that the fruit is not successfully recognized axis .

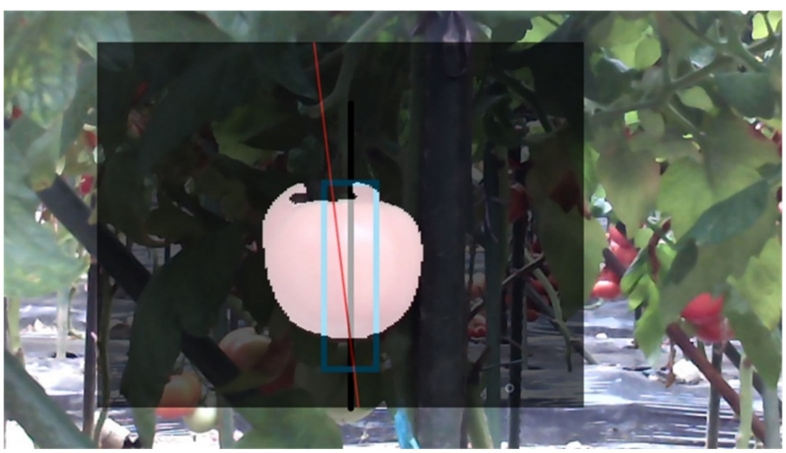


Figure10. Error analysis of centerline of fruit axis

Statistics of the recognition results of fruit axis are shown in the table 3, which shows that the success rate of fruit axis recognition of single fruit is 100% because of its single image and obvious features. When the image contains 2-3 fruits, the success rate is 92.8%. When the image contains more than 3 fruits, the success rate is 66.7% because of the problems of pixel area change and contour deformation in the process of separation.

Table 3 recognition results of fruit axis centerline.

Image attributes	Number of images	$k_1 \leq k \leq k_2$	$k<k1$ or $k>k2$	Accuracy
Single fruit	6	6	0	100%
2~3 fruits	42	39	3	92.8%
More than 3 fruits	21	14	7	66.7%
All images	69	59	10	85.5%

CONCLUSION

The clustered tomato growing in the greenhouse is selected as the research object, and a method to identify the axis of each single fruit for a clustered tomato.

(1)Based on morphological operation and Hough transform, the fruit separation operation is performed on all image sets. Among the 74 collected images, the recognition accuracy of images of a single fruit and 2~3 mature tomatoes was 100%, the recognition accuracy of images containing more than 3 tomato fruits was 80.7%, and the total recognition accuracy was 93.2%.

(2)Based on the moment feature, perform fruit axis recognition on all graphs.The success rate of fruit axis recognition of single fruit is 100% because of its single image and obvious features. When the image contains 2-3 fruits, the success rate is 92.8%. When the image contains more than 3 fruits, the success rate is 66.7% because of the problems of pixel area change and contour deformation in the process of separation.

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