Multiclass Fruit Packing System Based on Computer Vision

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Abstract. The traditional human-based fruit packing method is inefficient and costly. In response to the requirement of packing multiple fruits automatically in the present market, a multiclass fruit packing system based on computer vision is designed. Firstly, the image acquisition module captures images and passes them to the recognition module, which converts the RGB space of the image to the HSV color space and extracts the H and S components. Secondly, by using the morphological method to process the target areas, the class, size and position of the fruit are calculated. Finally, in the fruit packing control module, the manipulator automatically grasps different kinds of fruits into the different packing boxes according to the recognition results. The experimental results show that the accuracy of recognition is 93.73 %, the average recognition time of each image is 0.0402s. The accuracy of packing is 95.67% and the injury rate of fruit is 1.67%, which lay the foundation for fully automatic production of fruit.

1. Introduction

According to the calculation of the Chinese Academy of Agricultural Sciences, the market for Chinese fruit will reach 3.24 trillion yuan by 2024. The traditional manual fruit packing method is not only inefficient but costly, which becomes outdated at present.

Some researchers have carried out some experiments on packing fruit with the manipulator. Wang et al. [1] use the PLC controller and pneumatic driver to grab the fruit and transport it to the specified location. Xie et al. [2] developed the GFB-1 type fruit automatic weighing and packing machine, and its fruit injury rate is 1.7%. Lu et al. [3] designed a system for fruit sorting based on robot technology. However, these devices require human manipulation, and there are still limitations such as low intelligence and inability to be applied to automatic packaging in different situations.

About fruit recognition, reference [4] uses the K-Means algorithm, with the average recognition rate of lychee, grapes, and citrus up to 91.6 %, 93.6%, and 87.3%. However, it costs 1.365s to process data averagely, unable to meet the requirements of the manipulator to get the real-time location of fruit. Reference [5] introduced an algorithm for identifying citrus after analyzing RGB images. The results show that when the citrus is in the bright sunlight, the error of classification will occur severely. On the contrary, the recognition of objects in the HSV color space will have a better result [6].

To overcome the above shortages, this paper has proposed an algorithm to determine the class and real-time position of the fruit and design a system for fruit packing. It can improve the fruit packing efficiency and reduce the injury risk, which is of great significance in modern society.

2. Overall system design

The multiclass fruit packing system is combined by image acquisition module, image recognition module, fruit packing module, and status monitoring module in our research. They coordinate together to accomplish the entire process of fruit packing automatically.

2.1. Image acquisition module

The image acquisition module of this system grabs the image of fruit by the high-speed industrial camera. Through the connection between software Halcon and camera, It acquires images of different fruit from different backgrounds. There are burrs in the untreated image of fruit, and some area is brighter than others, showing the overexposure phenomenon. Also, the brightness of different backgrounds affects the recognition of fruit and the accuracy of packing.

2.2. Image recognition module

2.2.1 HSV

HSV (Hue, Saturation, Value) is a color space created by A. R. Smith in 1978 based on the intuitive nature of color, also known as the Hexcone Model, making the color information more effectively for image recognition [7], as is shown in figure 1. Pixels can be mapped from the RGB space to HSV space. We can get equation (1)~(3).

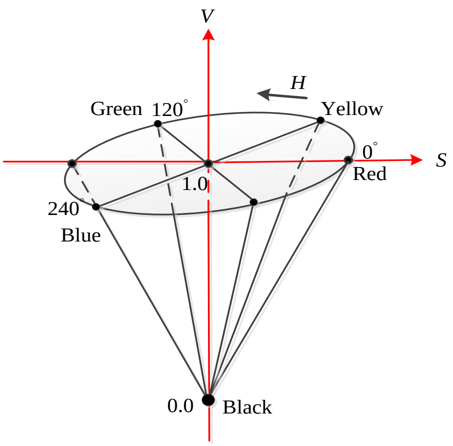

Figure 1. HSV color space

$$h = \begin{cases} \text{undefined} & \text{if } max = min \\ 60^\circ \times \frac{g-b}{max-min} + 0^\circ, & \text{if } max = r \text{ and } g \geq b \\ 60^\circ \times \frac{g-b}{max-min} + 360^\circ, & \text{if } max = r \text{ and } g < b \\ 60^\circ \times \frac{b-r}{max-min} + 120^\circ, & \text{if } max = g \\ 60^\circ \times \frac{r-g}{max-min} + 240^\circ, & \text{if } max = b \end{cases} \tag{1}$$

$$s = \begin{cases} 0, & \text{if } max = 0 \\ \frac{max-min}{max} = 1 - \frac{min}{max}, & \text{otherwise} \end{cases} \tag{2}$$

$$v = max \tag{3}$$

2.2.2 Recognition algorithm based on HSV

The recognition algorithm based on HSV is used to remove distractions in a complex environment and identify the class and position of fruit precisely. The process is shown in figure 2.

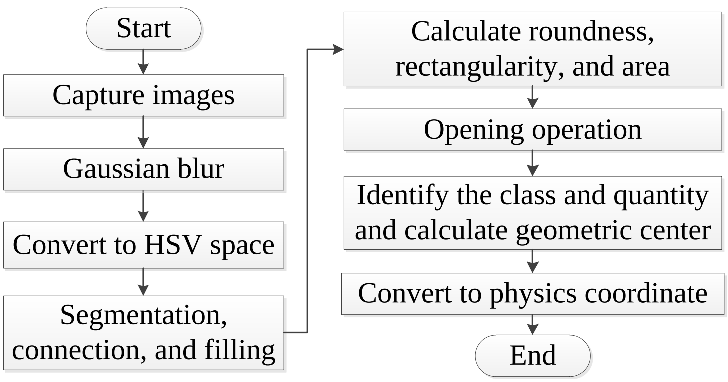

Figure 2. Process of the algorithm

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The specific steps are as follows:

Step 1. Capture images to be identified by Halcon in the video stream and preprocess it using a 9*9 Gaussian filter to suppress noise. The two-dimensional Gaussian function is shown as:

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{\frac{-(x^2+y^2)}{2\sigma^2}} \tag{4}$$

Where, x, y represents the horizontal and vertical coordinates, and the σ value of the 9*9 Gaussian filter is 1.88.

Step 2. Decompose the original RGB image into three single-channel images, and use the RGB to HSV equation to map the image from RGB space to HSV space.

Step 3: Use the characteristics that different color in HSV space has different value, H component in HSV space can distinguish different colors, while S component is insensitive to illumination variation to segment images and obtain target color domain.

Step 4: Connect the irregular domain obtained, and fill it to reduce errors of recognition.

Step 5: Calculate the roundness, rectangularity, and area of the connected domain using equation (5) and (6), then screen out the target areas.

$$Roundness=1-\frac{\frac{1}{F}(\sum\|p-pi\|-Distance)^2}{\frac{1}{F}\sum\|p-pi\|} \tag{5}$$

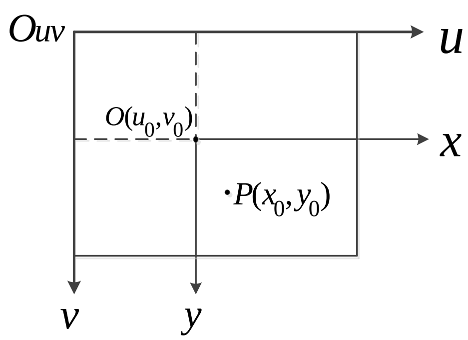
$$Rectangularity=\frac{S_0}{S_{MER}} \tag{6}$$

Where, p is the center of the area, pi the pixels and F the area of the contour. S_0 is the area of the object, S_{MER} the minimum circumscribed rectangle area.

Step 6. Perform the opening operation on the edges of the object area, that is, eliminating small regions that smaller than the circular structuring element such as lines or points, and followed with the Minkowski addition to smooth the boundaries, which do good to improve the calculated accuracy of the geometric center of the object area.

Step 7. Identify the class and quantity of fruit and calculate its geometric center.

Step 8. Convert the pixel coordinate of the image into the physics coordinate. The relationship between the pixel coordinate and the physics coordinate is shown in figure 3. And we can get the physics coordinate through equation (7).



$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} k_x & 0 & u_0 \\ 0 & k_y & v_0 \\ 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \tag{7}$$

Figure 3. Pixel coordinate and physics coordinate

Where, (u_0, v_0) is the coordinate origin of the physics coordinate. According to the above steps, the entire process from capture pictures to get the physics coordinate which can be identified by the manipulator is completed.

2.3. Fruit packing module

After getting the physics coordinate of fruit from the image acquisition module, the packing module controls the manipulator to complete the process of fruit packing. The three-axis multisense manipulator developed by Machine Age Company (Beijing) is used in this research, which is shown in figure 4.

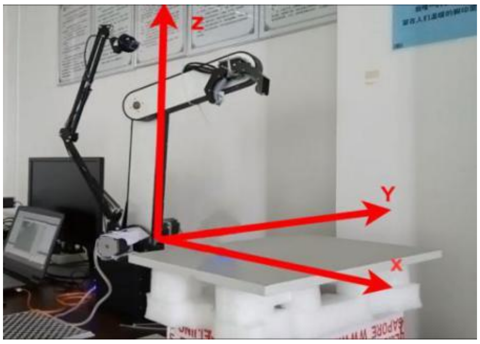


Figure 4. Three-axis multisense manipulator

Taking the Arduino Due as the control unit, the manipulator is connected with PC by USB cable. It controls three stepper motors by sending commands to the stepper motor drives. At the same time, three encoders feed signals back to Arduino Due respectively to complete the actions of the manipulator, such as moving, grabbing and putting fruit into boxes.

2.4. Status monitoring module

The PC software is prepared by using C++ language based on Microsoft Foundation Class Library. The camera is used in the status monitoring module and the whole process of picking fruit is shown on the man-machine interface.

Through the monitoring window, it is convenient for the staff to control the overall operating condition of the system, and do respondents to the situation of falling or misassembly during the process timely. At the same time, the module loads sensor data, position information of fruit into the database, which is beneficial to analysis the packing accuracy and injury rate of fruit, as well as the further improvements of the recognition algorithm and the control program of the manipulator.

3. Experimental results and analysis

In this paper, the HALCON17.12 computer vision library is used to accomplish multiclass fruit recognition, the Arduino Due is used to control the manipulator to pack fruit, the PC software is used to monitor the entire process. The fruit recognition algorithm is performed in the Inter Core i7-7700 HQ CPU.

3.1. Result of recognition

To verify the feasibility of the algorithm, a variety of RGB images of fruit such as apples, oranges, and guavas under different numbers and different illumination conditions were collected for experiments.

The edge of the apple obtained after the initial identification is rough and slightly larger than the actual, and the fruit pedicle is excluded in figure 5(a). After the next processing, the apple is extracted. The physics coordinates of apple1 and apple2 are (175.054, 543.72) and (227.537, 191.753) as they are shown in figure 5(b).

Due to the influence of yellow light, there are many irregular regions around the oranges in figure 5(c). After target screening, edge smoothing and so on, the orange is extracted and the physics coordinates is (206.699,282.031). The same is true for guavas image whose physics coordinates is (216.121,350.291).

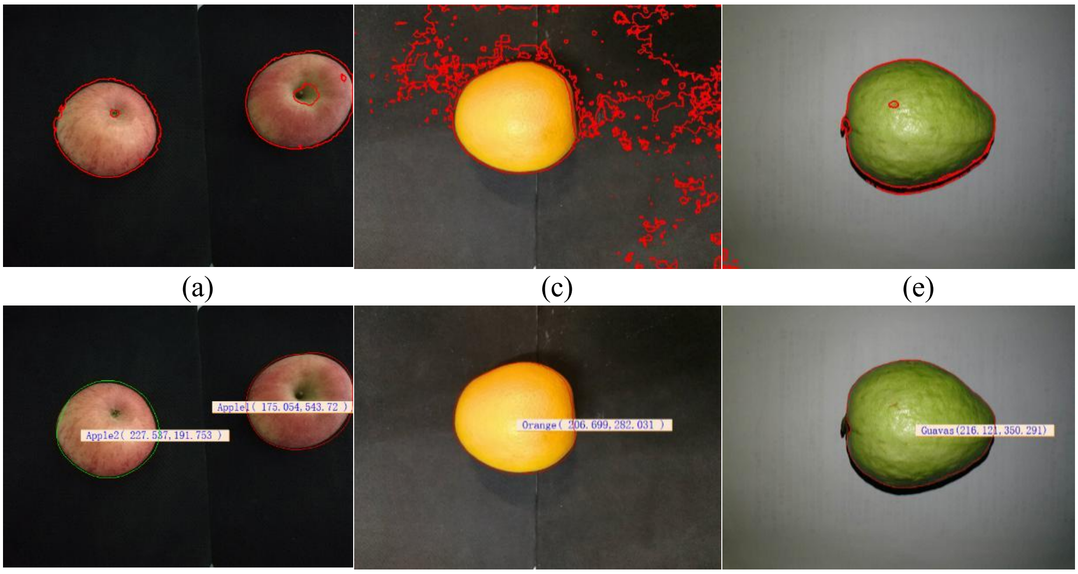


Figure 5. Results of recognition

3.2. Recognition time and accuracy analysis

Algorithmic time statistics are collected on 255 different fruit images. Taking the average time of running 10 times per image as the recognition time to reduce random errors.

From figure 6, it can be seen that the average recognition time of apple, orange and guava was 0.0411s, 0.03856s, and 0.0410s respectively. The maximum time is 0.0841s, the minimum time is 0.0281s, and the average time is 0.0402s, which shows that recognition time is short enough to satisfy the requirements of the manipulator for real-time positioning and grasping of fruit.

From figure 7, it can be known that 239 of the total 255 experimental samples are successfully identified, attaining an accuracy rate of 93.73%, which satisfies the requirements of a high recognition rate in the case of short recognition time.

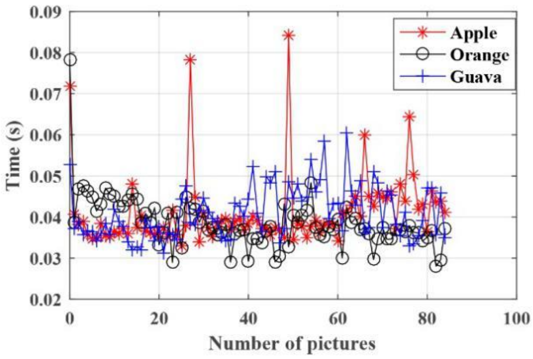


Figure 6. Statistical recognition time

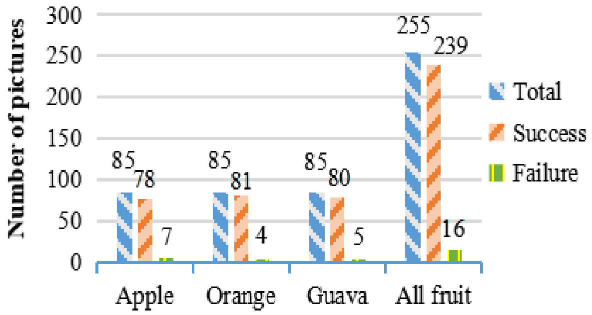


Figure 7. Statistical accuracy of recognition

3.3. Packing accuracy analysis

The fruit packing experiment carried out using the three-axis multisense manipulator shows that the accuracy of packing is 95.67% and the injury rate of fruit is 1.67%. By analyzing the result, we find that the reset error of the manipulator caused the calculation error of physics coordinate during the packing process. Also, the main cause of fruit injury is that the grasping force is too high for the fruit with higher maturity.

4. Conclusion

In this paper, this system is designed to packing different kinds of fruits automatically. The recognition algorithm can recognize fruit by utilizing the H component and the S component of the HSV color space that doesn't change as the light intensity change, which can effectively overcome the influence of light intensity and satisfy different situations. Using the HSV color space also improves the running speed of the algorithm while the recognition rate is high, which lays a foundation for the real-time acquisition of the fruit position for the manipulator to complete the full-automatic packing process. However, the large light intensity change still has a certain influence when recognizing different classes of fruits. With a higher packing accuracy rate, the multiclass fruit packing system in this paper has lower the fruit injury rate than the manual packing method and has great practical significance for the fruit production process. For the fruit with different maturity, to implement the dynamic adjustment of the grab pressure threshold to furthest reduce the fruit injure rate has become a follow-up direction of our research.

Acknowledgments

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