Recognition of garlic clove orientation based on machine vision

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Abstract. To address the problem of low garlic clove-head-turning rates in mechanized sowing of garlic, this study proposes an algorithm for identifying garlic clove orientation using machine vision. First, the algorithm performs preprocessing operations such as image enhancement and color space conversion; then, it identifies and labels the garlic clove regions by determining the connected regions. Each garlic clove region is derived for independent analysis, and three garlic clove features of each clove are calculated. Then, based on the distinctiveness of each feature parameter with clove recognition, comprehensive feature parameters are obtained by fusing the information of the three feature parameters. Finally, garlic clove head is identified on the basis of these comprehensive feature parameters. Furthermore, two garlic varieties, ‘Cangshan’ and ‘Jinxiang’ garlic, are tested by capturing images of both single and multiple garlic cloves. The experimental results indicate that the average recognition rate of the algorithm is 97.44%, and the average running time is 0.61 s. The correct recognition rate of ‘Jinxiang’ garlic is 94.51%, while that of ‘Cangshan’ garlic is 100%. In summary, the algorithm has strong adaptability and high accuracy, and it can provide a useful reference for an intelligent garlic clove-head-turning mechanism for garlic planters.

1. Introduction
To reduce labor costs and increase the level of large-scale garlic cultivation, mechanized garlic sowing has become a development trend. At present, the two main technical problems that restrict the promotion of mechanized garlic sowing are single clove seeding and clove upright-positioning seeding [1]. Upright-positioning seeding of garlic clove is critical for achieving uniformity of garlic emergence and high appearance quality of garlic [2]. Therefore, the rate of the upright-positioning cloves must be high during the garlic planting process; however, most existing garlic planters do not address this problem [3-4]. Therefore, a garlic clove orientation recognition algorithm based on machine vision is proposed in this study; this algorithm provides technical support for the development of intelligent garlic head turning device and has important practical significance.

Current garlic-head-turning methods can be divided into four categories according to their base principle: 1) mechanical structure turning according to the barycenter and shape features of garlic; 2) manual-intervention garlic head turning; 3) active head turning after detecting the clove orientation via
photoelectric sensors; and 4) active head turning after identifying clove orientation via image recognition. Turning methods using the first principle include a duckbill garlic head turning device, a three-stage cone hopper device, an automatic orientation device with a conical spiral catheter, or a rotary garlic single-grain-oriented seed extractor. The turning method using the second principle applies garlic boxes. Turning methods using the third principle comprise an infrared detection garlic recognition device and a laser optoelectronic photoelectric sensor for garlic orientation recognition.

For turning the head of garlic with regular shape, it is effective to use the barycenter and the shape features of garlic. By contrast, for the ‘Jinxiang’ garlic and other varieties with large differences in shape, the head-turning rate is not sufficiently high to meet the user’s requirements. In addition, although the head-turning rate of the manual intervention is high and adaptable, it is labor intensive and does not meet the requirements of comprehensive mechanization. The method of applying photoelectric sensors such as infrared detection to identify garlic clove orientation and then actively adjusting the head has the advantage of a high head-turning rate, but this method has poor adaptability to large differences in garlic shape. Using image recognition for garlic clove orientation and garlic clove head turning has the advantages of strong adaptability and a high head-turning rate, and it is expected to become the mainstream solution for the garlic-head-turning problem.

In recent years, image processing technology has been widely used in agricultural fields, such as fruit recognition and seed recognition, especially with the development of classifiers and deep learning algorithms for recognition of local features of objects. Some scholars have used image recognition to study garlic clove orientation. For example, Qingming Yang et al. used the difference in the area occupied by the head and tail in the grayscale map of garlic to determine the clove orientation; and Chun Fang et al. used deep learning for clove orientation recognition. These methods effectively recognize garlic cloves with regular shape, but they ignore the shape difference between varieties of garlic; therefore, these algorithms have low adaptability and a high misrecognition rate for ‘Jinxiang’ garlic.

In this study, the most important varieties of garlic, ‘Cangshan’ and ‘Jinxiang’ garlic, are used as the research object to identify the clove orientation using a multi-feature fusion method, aiming at improving adaptability, accuracy, and instantaneity of the clove recognition algorithm. Thus, an algorithmic reference is provided for garlic clove upright-positioning seeding devices based on machine vision.

2. Materials and method

2.1. Experiment design
The varieties of garlic used in the experiment are the most popular ‘Jinxiang’ garlic and ‘Cangshan’ garlic. For each garlic variety, 2.5 kg of cloves were used, and images of the garlic cloves were captured randomly without reusing. A total of 300 images were collected, which comprised by 100 single ‘Jinxiang’ garlic clove images, 50 multiple ‘Jinxiang’ garlic cloves images, 100 single ‘Cangshan’ garlic clove images and 50 multiple ‘Cangshan’ garlic cloves images, in BMP format with a resolution of 2048 × 1536 pixels. The entire test process used a computer with Windows 7 operating system, equipped with an Intel (R) Core (TM) i7-4790 CPU @ 3.60 GHz processor, and 8 GB of memory. The analysis software was MATLAB R2018a.

2.2. Image collection
For image collection, a USB3 vision industrial CCD camera with a maximum resolution of 2048H × 1536V and a 3-million-pixel industrial lens having a focal length of 6–12 mm was used. Then, 100 images of single ‘Jinxiang’ garlic clove, 50 images of multiple ‘Jinxiang’ garlic cloves, 100 images of single ‘Cangshan’ garlic clove, and 50 images of multiple ‘Cangshan’ garlic cloves were collected in BMP format.
2.3. Image preprocessing

The judgment of human eye on garlic clove orientation is based on the analysis of the garlic shape and rarely involves information such as color, texture, or color saturation. The same principle is applicable to machine vision. Therefore, in order to accurately identify the garlic clove orientation in real time, the acquired RGB image is subjected to preprocessing operations such as filtering, image enhancement, grayscale image conversion, and binarization. Then, connected regions are determined to label and extract the region of each clove; in the process, to prevent misrecognition of small connected regions as the clove region due to noise, the features of the connected region of garlic clove greater than a certain threshold are used for screening, thereby extracting accurate garlic clove regions. Finally, a binary map of each garlic clove region is derived for independent analysis. Compared with the whole image, the corresponding garlic clove region is smaller, so its recognition speed would be higher. Image preprocessing and extraction of garlic clove region are presented in Figure 1. Figure 1(a) shows the original RGB, and Figure 1(b) shows the effect of preprocessing such as image conversion and the function of measured image region attributes and garlic clove region labeling. Figure 1(c) shows a single garlic clove region extracted from the entire image shown in Figure 1(b).

The common sense knowledge is that when looking at the contour from a longer distance and details from a closer distance, the details have little effect on the overall feature recognition and would negatively affect recognition efficiency and accuracy. Nevertheless, in this study, a bilinear interpolation method is used to scale the original image before it is converted to grayscale, and it is found that the binarization effect is not reduced but greatly improved at a smaller scale. Figure 2 shows the influence of different scales on the binarization of garlic clove. In the process of reducing the original image scale from 1 to 0.2, the binarization effect gradually increases and becomes optimal at a reduction scale of 0.2-0.4 times the original image. In this study, the image obtained by reducing the original image by 0.3 times was selected for binarization transformation.

![Figure 1](image1.png)

**Figure 1.** Garlic clove region extraction process. (a) Original RGB image; (b) Regional labeling of garlic clove; (c) Single garlic clove region extracted.

2.4. Extraction of feature parameters

The Some pretreatments are performed on the garlic clove region to facilitate the analysis of the feature parameters of clove. First, a minimum circumscribed rectangle of garlic clove is drawn; then, two line segments are drawn through the center of each side of the rectangle to divide the garlic clove into four quadrants. The features of the clove structure are determined by the shape observation and statistics of ‘Jinxiang’ and ‘Cangshan’ garlic, respectively. The ratio of the projected area of the head and the tail of the garlic clove (feature 1), the ratio of the garlic clove area in the four quadrants (feature 2), and the corresponding minimum rectangular area (feature 3) are the most significant features for the recognition of the head of garlic clove. The three features are extracted as follows.
Figure 2. The influence of scale on clove regional binarization.

The process of extracting feature 1 according to the structural features of the garlic clove is shown in Figure 3. First, the operation of morphological opening is performed on the garlic clove binary map; the structural element adopted by the algorithm is a square of size 7. The result of the operation is presented in Figure 3(b). Second, the binary image obtained after the opening operation is subtracted from the original binary image, result is shown in Figure 3(c). Then, removed the small target, and the result is shown in Figure 3(d). Finally, the area of the target in the four quadrants of Figure 3(d) is calculated separately, and the quadrant that consists of the largest area (in most cases the other three quadrants have an area of 0) is the quadrant where the head of the clove is located.

Figure 3. Garlic clove feature 1 extraction. (a) Binary image; (b) Binary graph after opening operation; (c) Binary graph after subtraction; (d) Garlic clove feature 1.

The extraction process of feature 2 of garlic clove is presented in Figure 4. First, the long side of the circumscribing rectangle of the garlic clove region is the long-side direction of the clove. Then, 2 ends of the long-side direction is separately intercepted by 10% of the total length and the ratio of the area is calculated. Finally, the end of the smallest area is the quadrant where the head of clove is located.

Figure 4. Garlic clove feature 2 extraction. (a), (c) Garlic clove binary image, (a) Transverse clove; (c) Longitudinal clove. (b), (d) Garlic clove feature 2.
The extraction process of feature 3 of clove is presented in Figure 5. First, the areas of the four quadrants are calculated separately, and two quadrants with the smallest area are found. Then, the minimum circumscribed rectangle corresponding to these two quadrants is determined, and the area of the circumscribed rectangle is obtained. Finally, comparing the area of the two circumscribed rectangles, and the quadrant with the largest area of the circumscribed rectangle is the quadrant where the head of clove is located.

Figure 5. Garlic clove feature 3 extraction. (a) Garlic clove binary image. (b) Calculation of the area of clove in the four quadrants. (c) Find the circumscribing rectangle of two quadrants with small area. (d) Garlic clove feature 3.

2.5. Clove recognition algorithm
First, three feature parameters are proposed for the recognition of garlic clove orientation. Then, according to the saliency of each feature parameter, the corresponding weight coefficient is determined. Finally, the features of the weighting coefficients are summed to obtain comprehensive feature parameters, based on which the recognition of garlic clove orientation is completed. The specific steps of recognition algorithm are as follows:

1) Preprocess the image and convert it into a binary image; extract each garlic clove area and mark the minimum circumscribed rectangle; and divide the rectangle into four quadrants equally.
2) Calculate and analyze each garlic clove area to find the three feature parameters separately.
3) Using formula (1), fuse the three feature parameters to obtain the comprehensive feature parameters:

\[ T = 0.5 * T_1' + 0.3 * T_2 + 0.2 * T_3' \]  

where \( T \) is the comprehensive feature parameter; \( T_1', T_2, \) and \( T_3' \) are parameters of features 1, 2, and 3, respectively; and each coefficient in the formula is the weight coefficient of each feature parameter.
4) Determine the orientation of the garlic clove based on the relationship between the comprehensive feature parameter \( T \) and the threshold and on the placement of the garlic clove.

The recognition process corresponding to the above is presented in Figure 6.

3. Materials and method

3.1. Analysis of recognition result
Clove orientation recognition was performed for the 300 images collected from 508 cloves of garlic, including 229 cloves of ‘Jinxiang’ garlic and 279 cloves of ‘Cangshan’ garlic. The recognition results were presented in Table 1. The number of garlic cloves that were correctly recognized was 495, recognition rate was 97.44%, within an average running time of 0.61 s. The average correct recognition rate of ‘Jinxiang’ garlic was 94.51% and that of ‘Cangshan’ garlic was 100.00%.
Figure 6. Visualization flow chart corresponding to the garlic clove recognition algorithm. (a) Binarization and labeling garlic clove area. (b) Extract each garlic clove area and divide it into four quadrants. (c) Extraction Feature 1. (d) Extraction Feature 2. (e) Extraction Feature 3. (f) Recognition result.

Table 1. Recognition results of garlic clove orientation

| Test                                      | Total number of garlic cloves | Number of correct recognition cloves | Average running time/s | Recognition rate/% |
|-------------------------------------------|------------------------------|-------------------------------------|------------------------|--------------------|
| 100 images of single ‘Jinxiang’ garlic clove | 100                          | 96                                  | 0.502                  | 96.00              |
| 50 images of several ‘Jinxiang’ garlic cloves | 129                          | 120                                 | 0.718                  | 93.02              |
| 100 images of single ‘Cangshan’ Garlic clove | 100                          | 100                                 | 0.502                  | 100.00             |
| 50 images of several ‘Cangshan’ Garlic cloves | 179                          | 179                                 | 0.718                  | 100.00             |
| Total                                     | 508                          | 495                                 | 0.61                   | 97.44              |
Results show that the recognition rate of the two varieties is very different. The rate for ‘Cangshan’ garlic clove being significantly higher than that of ‘Jinxiang’ garlic. This is mainly because ‘Cangshan’ garlic consists of 4-6 cloves per garlic, and its cloves are large and neat; moreover, its clove has a regular shape and the sheath of clove is long and hard. By contrast, each garlic of ‘Jinxiang’ has many cloves (more than 6), and ‘Jinxiang’ garlic cloves have irregular shape and the sheaths of the clove are short and soft, which have effect on the feature 3 of ‘Jinxiang’ garlic cloves, leading to the false recognition of clove orientation.

3.2. Algorithm adaptability analysis
To verify the adaptability of the proposed algorithm, the two varieties of garlic, ‘Cangshan’ garlic and ‘Jinxiang’ garlic, were tested. In addition, an experiment was conducted on the case where each image contained several cloves which placed randomly. The orientation of four ‘Cangshan’ garlic cloves in a single image and four ‘Jinxiang’ garlic cloves in a single image are presented in Figure 7. The
experimental results indicate that the proposed algorithm has good adaptability to garlic varieties, the number of cloves in each image, and the order of placement of the cloves.

3.3. Analysis of algorithm recognition error case

As shown in Figure 8, the proposed algorithm yielded a case of erroneous recognition of the clove. The reasons for the false recognition are as follows:

1) As shown in Figure 8(a), the head sheath of the clove of the ‘Jinxiang’ garlic is fine and bent to the inside under the action of an external force, and the clove tail has an elongated sheath protruding outward and is more prominent than the head sheath.

2) As shown in Figure 8(b), in feature 1 extraction of the garlic clove, the tail garlic is incorrectly identified as the head of the clove.

3) The results of feature 2 extraction of the garlic clove are shown in Figure 8(c). The cross-sectional area of the tail is close to the head, resulting in feature 2 not correctly reflecting the garlic clove orientation.

4) In feature 3 extraction of the garlic clove, as shown in Figure 8(d), because the tail area of the garlic clove is small and its smallest circumscribed rectangular area is large, the garlic tail is falsely identified as the head.

The above analysis shows that the garlic clove orientation is misidentified when the clove sheath was bent to the inside or broken. However, this kind of garlic clove is rare, so the false recognition rate of garlic clove orientation using this algorithm is low.

Figure 8. False recognition of garlic clove orientation.

4. Conclusions

The proposed recognition method of garlic clove orientation uses preprocessing operations such as image enhancement and color space conversion, searches for the garlic clove region by determining the connected regions, and derives each garlic clove region for independent analysis. These processes can effectively improve the recognition speed and accuracy.

Based on the analysis of the features of garlic cloves, three feature parameters of the garlic clove are proposed. Based on the significant difference between the feature parameters to the recognition of clove, the information of the three feature parameters is fused to obtain comprehensive feature parameters, based on which the garlic clove orientation is identified.

In the tests conducted on ‘Cangshan’ and ‘Jinxiang’ garlic varieties, an average recognition rate of 97.44% was obtained within an average running time of 0.61 s. Furthermore, the correct recognition rate of ‘Jinxiang’ garlic clove was 94.51% and that of ‘Cangshan’ garlic was 100%.

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