Image segmentation method of adherent corn ears based on improved watershed

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Abstract: Aiming at the problem of corn ears adhering in the process of corn test, the images of adherent corn ears were taken in the whole plot as our research object, and image segmentation method of adherent corn ears based on improved watershed was studied. We mainly proposed an improved watershed segmentation method based on limit corrosion and convex hull detection for common adherent corn ears, such as weak adherent corn ears, ring adherent corn ears, strong adherent corn ears and mixed adherent corn ears. The method can not only divide a variety of common sorts of the adherent corn ears, but also quantitatively calculate the lengths and diameters of the corn ears after the effective correction of the image distortion and the two-dimensional calibration of the image. Experimental results showed that the improved watershed segmentation method could achieve automatic segmentation for common adherent corn ears. The average accuracy rate of the ear length is 97.79%, and the average accuracy rate of the ear diameter is 96.70%. The accuracy rate of the whole system has reached 97.24%. This study provided an important technical basis for the measurement of characteristic parameters of adherent corn ears, and also an important solution to the segmentation problem of class cylinder.

Keywords: corn test, adherent corn ears, improved watershed, image segmentation

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1 Introduction

Corn test is an important link in the process of genetic breeding of corn crops. It is very important to rapidly and accurately measure the characteristic parameters of corn ears for improving the technology of scientific seed selection and breeding efficiency (Wu et al., 2016). Traditional corn test work mainly relies on manual identification leading to many disadvantages, such as large workload, low efficiency and low precision. Although some of the corn test equipment can automatically collect and identify the characteristic parameters of corn ears, most equipment is multi-channel mode. For the corn ears in the whole plot, high-throughput automated pipeline without artificial adjustment or put the corn ears on the portable object stage arbitrarily or the overall dumping the corn ears cannot avoid the problem of corn ears adhesion. Therefore, in order to realize the high-throughput automatic measurement of the characteristic parameters of the corn ears and improve the measurement precision and efficiency, the problem of automatic segmentation of the adherent corn ears needs to be solved urgently.

In recent years, researchers have applied the machine vision technology to achieve the high-throughput automatic measurement of characteristic parameters of the corn ears (Wang et al., 2014; Li et al., 2016; Liu and Chen, 2014; Liu et al., 2011; Manickavasagan et al., 2008; Pearson, 2009). In order to solve the problem of corn text, researchers have proposed a variety of adhesion image segmentation methods, mainly including corrosion expansion method (Li et al., 2010; Xiao et al., 2015), watershed improvement algorithm (Gao, 2015; Ng et al., 2007; Rao and Srinivas, 2006), shape feature matching method (Zhu et al., 2009; Cai and Pang, 2011), contour

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bump detection method (Wang et al., 2015; Wei and Zhao, 2010) and so on. Weickert et al. (2001) proposed to use the partial differential equation for image denoising and edge enhancement, which combined with the method of watershed segmentation and regional merging, but the segmentation effect for the general noise images is not obvious because of the distortion phenomenon. Xunyi et al. (2010) proposed a method based on the common area and grain contour to find the dividing point, which realized the automatic segmentation of the image of the adhesive maize grains, but the holes of maize grains could easily cause error segmentation and low accuracy. Zhou Jinhui et al. (2015) proposed a method of segmenting the contours of the adherent corn ears according to the freeman chain code tracking the gradient changes of the contours, but only the tandem adhesion of the rules can be segmented and the other types of adhesions cannot be segmented. In this paper, an improved watershed segmentation method based on limit corrosion and convex hull detection was proposed to solve the problem of adherent corn ears which are arbitrarily placed in the process of corn test. The method is fast and efficient and can solve the problem of weak adherent corn ears, ring adherent corn ears, strong adherent corn ears, mixed adherent corn ears and so on, which improves the measurement efficiency of the characteristic parameters of corn ears in the plot.

2 Materials and methods

2.1 Image collection and pretreatment

2.1.1 Definition of adherent corn ears

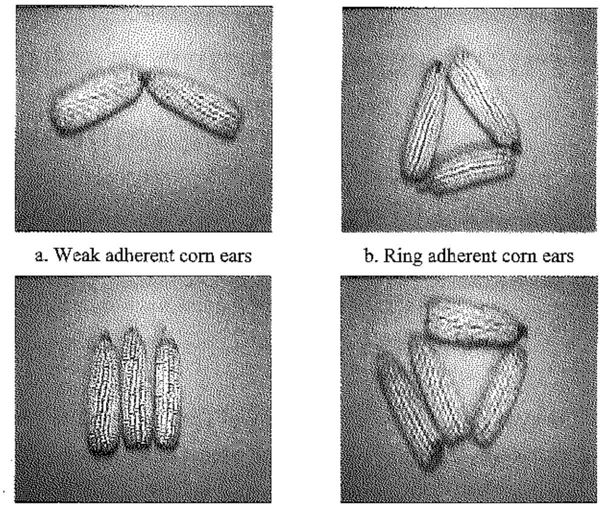
Weak adherent corn ears: the adhesive part, by the way of head-to-tail connection, is small and do not form an adherent ring.

Ring adherent corn ears: three or more than three corn ears form a ring-shaped adhesive structure through the pattern of weak adhesion.

Strong adherent corn ears: two or over two corn ears adhere through side by side, and the adhesive area is large but no more than the diameter of one corn ear.

Mixed adherent corn ears: the adhesive way combines of weak adhesion, ring adhesion and strong adhesion.

Several common images of adherent corn ears are shown in Figure 1.



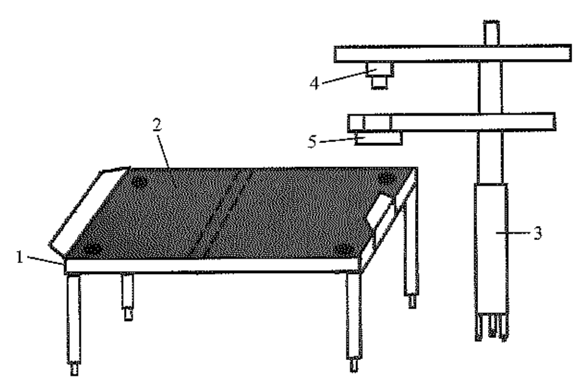
a. Weak adherent corn ears b. Ring adherent corn ears

c. Strong adherent corn ears d. Mixed adherent corn ears

Figure 1 Images of adhesive corn ears

2.1.2 Image collection

The image collection equipment is shown in Figure 2, which consists of a carrier support, an objective table, a camera and light source bracket, a high resolution 4608×3288 CCD camera and a light source. The carrier support is used to support the objective table, and the corn ears are placed in the center of the 1.2 m×0.9 m objective table. The CCD camera and the light source are respectively placed in the top position and the middle position of camera and light source bracket. The images are divided into two categories. One kinds are the small format images including 2-5 adherent corn ears, which are using for the study of segmentation algorithm for a variety of adherent corn ears, and the resolution ratio of the images are 1024×768. The other one kinds are large format images including 40 adherent corn ears, which are served as the study sample for calibration and algorithm validation.



1. Luggage carrier 2. Objective table 3. Camera and light source bracket 4. Camera 5. Light source

Figure 2 Image collection equipment

2.1.3 Two-dimensional image calibration

The purpose of the two-dimensional image calibration is to correspond the distance in the image to the actual distance and find the proportion of the image, in that we can directly measure the real ear length and diameter. Distortion will cause the image loss for the camera perspective. In brief, the object is a straight line, but the image is significantly distorted. In order to accurately calibrate the image, the distortion correction is essential.

This paper regarded the 9×6 black and white grid board as the two-dimensional calibration board, in which the real length p of each small square is 20.0 mm. We found the black and white lattice points on the calibration plate by the sub-pixel level corner detection, and connected and calculated the number of long pixels of all valid square latches according to the set threshold to find the average value L. Get the system calibration parameter a is

$$a=L/p$$

After a large number of calculations, we concluded that in the 1.2 × 0.9 m format, a=3.85, and in the 0.8× 0.6 m format, a=5.53.

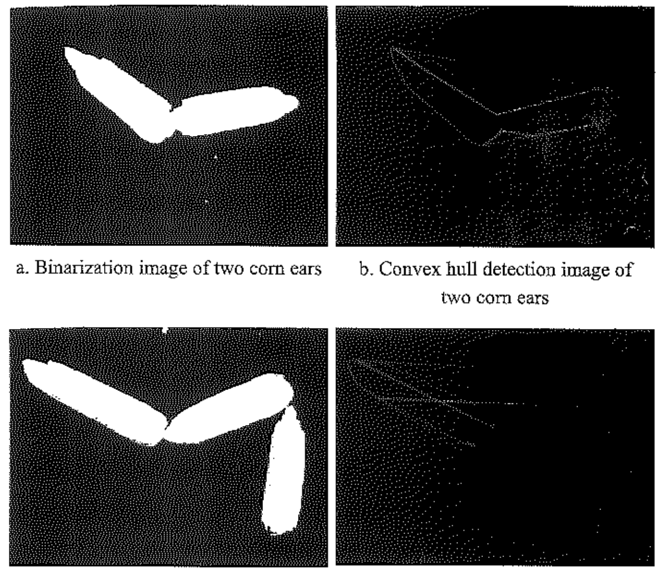
2.1.4 Image preprocessing

Image preprocessing includes image denoising and image binarization. In order to eliminate the noise in the image, the method of median filter was used into the image. In order to effectively binarize the image, the RGB histogram of the image floor, the corn ears and the shadow of the corn ears were analyzed, and the image of adherent corn ears was binarized according to feature of the RGB histogram.

2.2 Study on image segmentation algorithm

2.2.1 Convex hull detection method

There must be a convex defect due to the adhesion in the corn ears. According to the convex defect, we can find the points which have the longest distance to the convex hull line and take them as the dividing points. The adherent corn ears are divided by the method of linking the dividing points (Xi, 2013). Draw the contours of the adherent corn ears, as shown in Figure 3, where the red marks are the dividing points. From the analysis of Figure 3, it can be seen that the method of convex hull detection has a good effect on the two adherent corn ears, but it cannot find the dividing points correctly for the three adherent corn ears or over three adherent corn ears. Therefore, the applicability of convex hull detection method is not good enough, and the method will have some damages to the contours of the adherent corn ears.



a. Binarization image of two corn ears b. Convex hull detection image of two corn ears

c. Binarization image of three corn ears d. Convex hull detection image of three corn ears

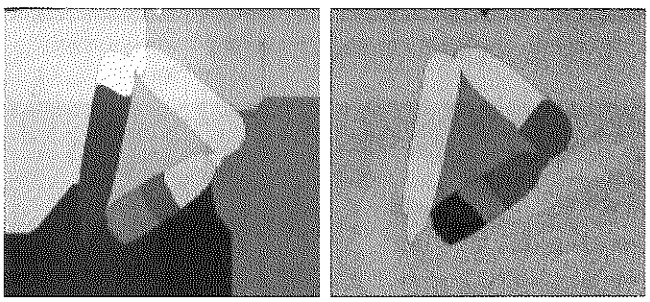
Figure 3 Images of convex packet inspection

2.2.2 Watershed algorithm

The method of watershed algorithm (Yan and Wang, 2012) is a commonly used technique in image segmentation. In the traditional watershed algorithm, each local minimum point corresponds to one segmentation region in the image, which contains both the true target minimum point and the pseudo-local minimum point which is introduced by background noise and texture details. The traditional watershed method easily leads to over-segmentation. The method of improved watershed is to improve the accuracy of watershed algorithm mainly based on the adaptive filter and the marker extraction (Yilihamu, 2013; Yu et al., 2011). However, in the actual process of corn test, the phenomenon of the corn kernels shattering is obvious, which easily causes over-segmentation by marking the location of the corn kernels shattering. Figure 4 is the effect image of the adherent corn ears by using the method of watershed segmentation.

2.3 Watershed segmentation based on limit corrosion and convex hull detection

Firstly, we should remove the disturbance of maize kernels and other impurities by the method of limit corrosion, and corrode the adherent corn ears all the time without any contours loss until each ear is divided. Secondly, we should detect the image after corrosion by the method of convex hull detection, and find the points which have the longest distance to the convex hull line (dividing points). Finally, we should mark the binarization image by linking the dividing points and invoke the watershed algorithm, so as to achieve the segmentation of the adherent corn ears. Figure 5 is the flow diagram of the algorithm.



a. Image of traditional watershed algorithm b. Image of improved watershed algorithm

Figure 4 Images of watershed algorithm

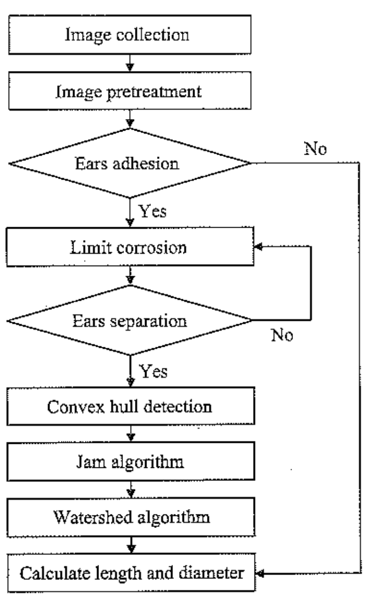


Figure 5 Image of algorithmic process

2.3.1 Judgment of adherent corn ears

Select the shape factor which describes the target boundary as the judge basis of the adherent corn ears (Li et al., 2015). The shape factor SF is defined as:

$$SF = \frac{4(2\lambda + \pi - 2)^2 S}{\lambda \pi L^2}$$

where, S is the area pixel value of a connected region; L is the perimeter pixel value of the connected region; λ is the average value of the ratio of length and diameter of the corn ears.

Measure the area pixel value of the biggest corn ear and mark it as $S_{\max 0}$. Corrode the adherent corn ears continually until they are disappeared. Record the number of corrosion as n and the area pixel values of the corn ears after each corrosion as $S_{\max i}$ $(0<i<n)$. The specific steps are as follows:

(1) Extract the area pixel value and the perimeter pixel value of each corn ear and calculate the shape factor.

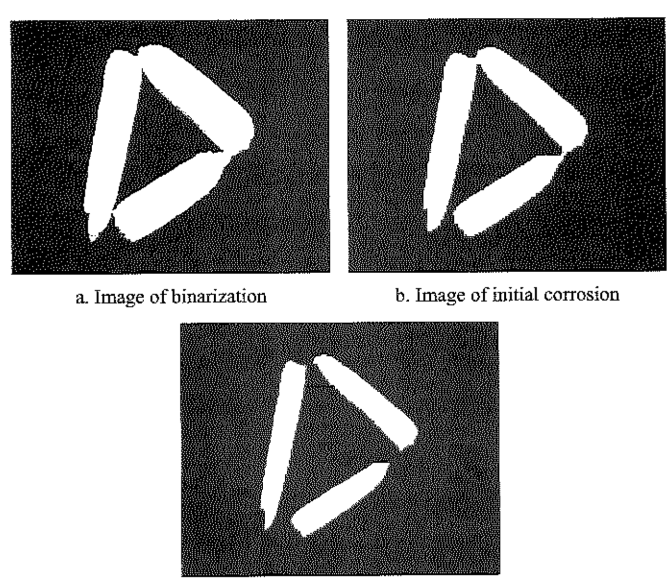
(2) If the shape factor of each contour $SF>SF_0$ and $S<S_{\max 0}$, it can be judged that there are no adherent corn ears in the image and then the corn ears contour can be extracted. On the contrary, the image of the adherent corn ears should be corroded.

(3) Extract the area pixel value and the perimeter pixel value of each corn after the front corrosion and calculate the shape factor.

(4) If the shape factor of each contour $SF>SF_0$ and $S<S_{\max i}$ $(0<i<n)$, it can be judged that the adherent corn ears in the image has been separated. On the contrary, the image of the adherent corn ears should continue be corroded after the front corrosion.

(5) Repeat the steps 3) and 4) until it can meet the condition in 4), or the number of the corrosion times has reachedn.

Figure 6 is the corrosion effect image. The first corrosion can be achieved to remove the impurities such as the kernels shattering, and the final corrosion result can separate the adherent corn ears.



a. Image of binarization b. Image of initial corrosion

c. Image after final corrosion

Figure 6 Effect images of corrosion

2.3.2 Watershed marked with limit corrosion

Firstly, we should separate the adherent corn ears by the method of limit corrosion and detect the edge of the image after the final corrosion. The result of the edge detection is applied to the original binarization image to find the dividing points. Secondly, we should invoke the watershed algorithm which is depicted on the original binary image with black lines. Finally, we can separate the adherent corn ears, and the black lines are formed in the image, as shown in Figure 7.

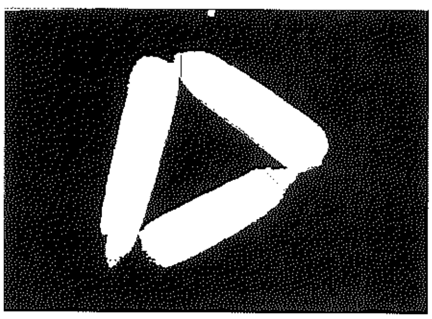


Figure7 Images of watershed marked by ultimate erosion

From the analysis of Figure 7, it can be seen that the contours of the adherent corn ears are separated by the formed black dividing lines in the image. But the position of the dividing lines is somewhat deviated, leading to contour deformation of the corn ears. The reason is that convex hulls can be formed when corrosion occurs from the outer contour of the adherent parts until the adherent parts are separated. The size and position of the convex hulls cause the result deviation after expansion and result in the position deviation of the dividing lines.

2.3.3 Convex hull detection and stuck algorithm

The method of convex hull detection can represent the contours of the adherent corn ears, and the method of stuck algorithm is the way to find the two points whose distance is farthest between the contours. The two points whose distance is farthest must be a pair of points on the convex hull, as shown in Figure 8, q_a and q_b are a pair of points on the convex hull P. L_a and L_b are two parallel lines which are respectively pass the points q_a and q_b. When the two lines L_a and L_b respectively slide along the arc C_a and C_b, they do not touch the other points on the convex hull, which proves that q_a and q_b are a pair of points whose distance are longest on the convex hull. Connect the two points, we can get the longest straight line on the contour.

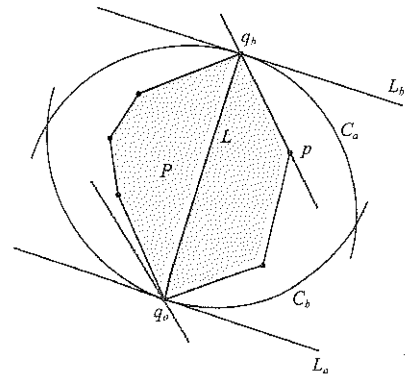
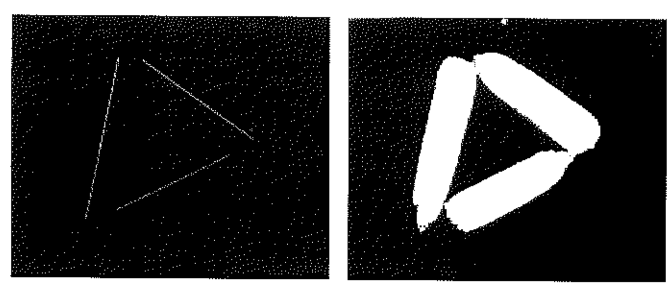


Figure 8 Image of stuck algorithm

For the corn ears after corrosion, straight lines passing through the corn ears are obtained. We should extend the straight lines according to the size of the corrosive element, and the dividing lines passing through the original corn ears are obtained. The accuracy rate of the segmentation method is high and the convexity problem is improved. Figure 9 shows the segmentation effect of adherent corn ears with the method of improved watershed algorithm based on limit corrosion and convex hull detection. The method has good overall effect in contour extraction and no serious deviation of dividing lines, and the watershed segmentation lines can be extracted accurately. Therefore, the improved watershed method based on limit corrosion and convex hull detection can effectively separate the adherent corn ears.



a. Lineation of stuck algorithm b. Watershed marked with stuck algorithm

Figure 9 Images of watershed based on ultimate erosion and convex packet inspection

3 Experiments and results

3.1 Experiment methods

Taking many crossbreed adherent corn ears, which are arbitrarily placed, as our research objects, we collected the image of adherent corn ears and regularized it. The image was calibrated by the method of two-dimensional (2D) and preprocessed as well. We separated the adherent corn ears with the method of improved watershed segmentation algorithm based on the limit corrosion and convex hull detection and extracted the contours of each corn ear in the binary image after the adherent corn ears were separated. The pixels length and pixels diameter of the corn ears were obtained by the method of creating minimum external rectangle. The actual length and diameter of the corn ears were acquired according to the 2D calibration parameters and the stereoscopic projection correction model (Yang, 2008; Duan et al., 2014).

3.2 Segmentation algorithm accuracy verification

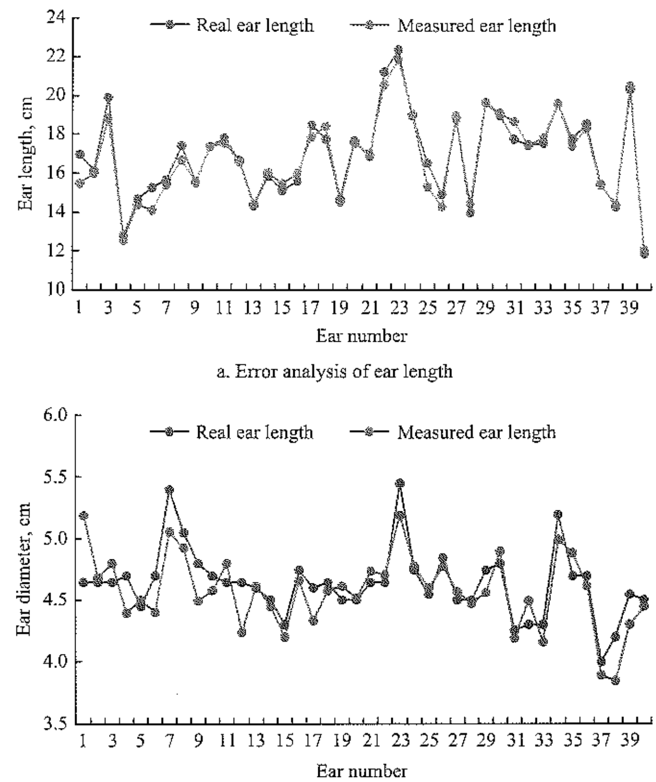
The error of the segmentation algorithm was determined by the length and diameter of the corn ear. In this paper, we measured the length of 40 corn ears in all kinds of adhesion with the segmentation algorithm and the true length of the 40 corn ears. The average error was calculated by comparing the true values with the measured values, as shown in Table 1. The results showed that the average accuracy of weak adherent corn ears is 97.23%, the segmentation accuracy rate of ring adherent corn ears is 96.34%, the segmentation accuracy rate of strong adherent corn ears is 96.98%, and the segmentation accuracy rate of mixed adherent corn ears is 97.13%.

Table 1 Error of segmentation algorithm validation

Adhesion Classification	Adhesion type	Average Error
Weak adhesion	Head-Head	0.03
	Head-Foot	0.04
	Foot-Foot	0.01
	Head-Body	0.03
	Foot-Body	0.03
Ring adhesion	Three Rings	0.04
	Four Rings	0.04
Strong adhesion	Two Ears	0.01
	Three Ears	0.04
	Four Ears	0.04
Mixed adhesion	Strong mixed adhesion	0.03
	Weak ring mixed Adhesion	0.04
	Strong ring mixed Adhesion	0.03

3.3 System accuracy verification

In the actual environment of corn test, the accuracy of the algorithm after the combination of two-dimensional calibration and segmentation algorithm was verified. We measured the length and diameter of 40 adherent corn ears with the method of improved watershed algorithm and the true length and the true diameter of the 40 corn ears. The error was calculated by comparing the true values with the measured values, and the results are shown in Figure 10. From the analysis of the whole system error, it can be seen that the average accuracy of length is 97.79%. The average accuracy rate of diameter reached 96.70%. The accuracy of the whole system can reach 97.24%.



a. Error analysis of ear length

b. Error analysis of ear diameter

Figure 10 Error analysis of the system

The results showed that the accuracy of the system is high, but the errors of partial measuring results are large, mainly because some of the adherent situations are too serious and also because of the rapid expansion of the individual minimum value during the expansion process. In the segmentation results, the diameter error of the corn ears is larger than the length error of the corn ears, which is due to the fact that the actual shape of the corn ears is different, and the measuring position of the diameter is difficult to determine and that is also caused by the projection correction model.

4 Conclusion

Taking many crossbreed adherent corn ears, which are arbitrarily placed, as the research object, we separated the adherent corn ears with the method of improved watershed segmentation algorithm based on the limit corrosion and convex hull detection. The results showed that the method could effectively divide the adherent corn ears and the length and diameter of the adherent corn ears were calculated quantitatively. The average accuracy of weak adherent corn ears is 97.23%, the segmentation accuracy rate of ring adherent corn ears is 96.34%, the segmentation accuracy rate of strong adherent corn ears is 96.98%, and the accuracy of mixture adherent corn ears is 97.13%. The average accuracy rate of the ear length is 97.79%, and the average accuracy rate of the ear diameter is 96.70%. The accuracy rate of the whole system reached 97.24%, which can meet to the requirement of automatic corn text.

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