DESIGN AND EXPERIMENT OF RECOGNITION SYSTEM FOR COATED RED CLOVER SEEDS BASED ON MACHINE VISION
/
基于机器视觉的包衣红三叶种子识别系统的设计与试验

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DOI: https://doi.org/10.35633/inmateh-66-06

***Keywords:** Coated seeds of red clover; Seed coating; Machine vision; Image processing; LabVIEW*

ABSTRACT
While studying the coating theory, due to the lack of the support of the rapid identification and detection device for coated red clover seeds, for a long time, we have mainly relied on manual visual inspection to sort qualified coated seeds, only relying on human eyes to identify the cause of low efficiency, high wrong classification rate and high labor intensity. In order to identify the coated red clover seeds quickly and efficiently, a set of intelligent identification and detection system for coated red clover seeds was designed. First of all, by building a machine vision shooting platform to ensure that the light source and other shooting conditions are consistent, the images are transmitted to Vision Assistant 2018 for image processing. Secondly, two image processing algorithms are designed to process qualified coated seeds and damaged coated seeds respectively. Finally, an identification and detection algorithm is proposed, which uses LabVIEW2018 as the host computer to identify the qualified number and the damaged number. Taking red clover seeds as the test object, the test results show that the entire system takes about 1 second to collect and process a single image; the recognition accuracy of qualified coated seeds and damaged coated seeds is above 96% and 85%. The identification and detection system realizes the nondestructive detection of coated seeds, and provides theoretical basis and technical support for the later research on the optimal seed coating process, deepening the theoretical research of the coating machine and improving the degree of automation.

摘要
在对包衣理论进行研究的同时，由于缺少包衣红三叶种子快速识别检测装置的支持，长期以来主要依靠人工目测分选合格的包衣种子，仅靠人眼识别效率低、错分率高、劳动强度高，为此设计了一套包衣红三叶种子智能识别检测系统，针对包衣红三叶种子进行识别。首先，通过搭建机械视觉拍摄平台，保证光源等拍摄条件一致，传输图像至Vision Assistant 2018 进行图像处理。其次，设计两种图像处理算法，分别对合格包衣种子以及破损包衣种子进行处理。最后提出了一种识别检测算法,采用LabVIEW2018 作为上位机对合格数以及破损数进行识别。以红三叶种子为试验对象，试验结果表明：整套系统对单幅图像采集和处理时间约为 1s；对合格包衣种子以及破损包衣种子识别准确率分别在 96%和 85%以上。该识别检测系统实现了对包衣种子的无损检测，为后期研究种子最佳包衣工艺，深化包衣机理论研究以及提高自动化程度提供了理论基础与技术支持。

INTRODUCTION
Red clover is one of the most widely cultivated legume pastures in the world, and is a famous high-quality pasture. Red clover has a high nutritional value. According to measurement, when flowering, the dry matter contains 17.1% crude protein, 3.6% crude fat, 21.5% crude fiber, 47.6% of nitrogen-free extract, 10.2% crude ash. It is also rich in various amino acids and vitamins, the grass is soft and the palatability is good, all kinds of livestock like to eat. In addition, red clover has strong resistance to extreme weather and its colorful flowers are excellent ornamental grass, and its medicinal value cannot be ignored.

Seed coating is a technique to cover seeds with external agents to upgrade their performance, handling, and plant establishment (*Li, 2016*). A specific coating process is used to make the surface of the seed and the coating agent evenly contact, and wrap it to form a smooth and firm medicinal film. Through mechanical processing, small spheres of uniform size and regular shape (including true circle, ellipse, oblate, etc.) are made. The coating agent can contain a variety of ingredients. According to specific environmental factors, proper adjustment of the dosage of ingredients can improve the ability of seeds to resist drought, cold, salt and alkali, and prevent soil-borne diseases (*Shao, 2018*).

Experiments have proved that the germination rate of red clover coated seeds is higher than that of ordinary red clover seeds, and the adaptability is stronger. Theoretically, the germination rate can reach more than 90. While studying the qualified rate of coating under different parameters, due to the lack of support for rapid identification and detection of coated seeds, we have mainly relied on manual visual inspection to sort qualified coated seeds and calculate the qualified rate of coating for a long time, relying only on human eyes has low recognition efficiency, high misclassification rate, and high labor intensity (*Xing, 2019*). The development and design of an intelligent identification and detection system for coated red clover seeds to improve the efficiency of coating research is a problem that needs to be solved urgently (*P.T, 2016*).

In this paper, a real-time algorithm based on LabVIEW was proposed to improve the detection speed and accuracy. A machine vision test platform to take real-time images of images is built (*Xiong, 2019*). Two image processing algorithms are designed to process qualified coated seeds and damaged coated seeds respectively. Transfer the image to system, identify the seeds, and calculate the qualified rate of coating, so as to explore the best coating process and enrich the theoretical research of the coating machine.

MATERIALS AND METHODS

Structure of coating machine

The seed coating machine is composed of a coating pot, an inclination adjusting device, a rotary motor and a vibrating table (*Sun, 2017*). The overall structure of seed coating machine is shown in Fig.1.

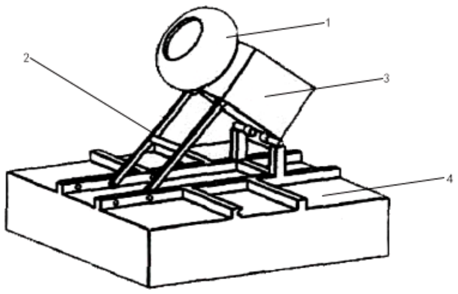

Fig.1 - The overall structure of seed coating machine

1- Coating pot; 2- Inclination adjusting device; 3- Rotary motor; 4- Vibrating table

Before coating, the inclination angle of the coating pot is adjusted by the inclination angle adjusting device, and the seeds and powder are respectively sent into the coating pot. When coating, the rotating motor starts to rotate, thus driving the coating pot to rotate at high speed. The shaking table vibrates continuously to make the seed coated quickly under the action of vibration force field (*Zhu, 2012*). During the coating process, the liquid is continuously supplied. Finally, the whole coating process is completed.

Machine vision experiment platform

In the process of shooting coated seeds, different light conditions and shooting angles have a great impact on the recognition effect (*Deng, 2017*). In order to improve the accuracy of recognition algorithm, a machine vision experimental platform is built. The mechanical vision experiment platform consists of USB camera, chassis, light source, bracket and image processing system. The mechanical vision experiment platform is shown in Fig.2.

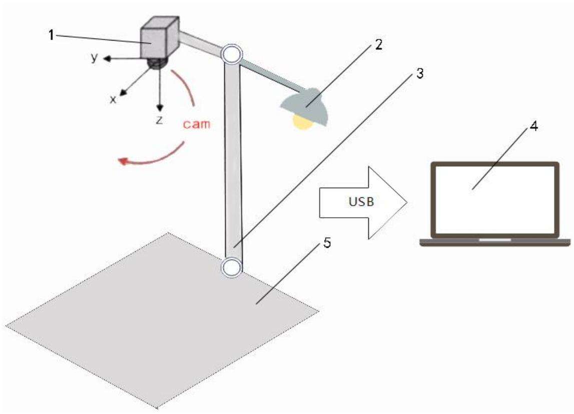

Fig. 2 - The mechanical vision experiment platform

1- USB camera; 2- Light source; 3- Bracket; 4- Image processing system; 5- Chassis

Red clover coated seed model template

Taking red clover seeds of leguminous forage as the object, the coating material is phosphorus potassium compound fertilizer. During the growth of seeds, the compound fertilizer dissolves in water, which not only does not affect the growth of seeds, but also creates nutritional conditions for their growth. Through the coating machine, adding water and adhesive properly, under the joint action of vibration force and rotation force, the compound fertilizer fully contacts with the seed, and finally evenly wraps the surface of the seed, forming a small sphere with uniform size and regular shape (*Taylor A.G, 2008*). The coated seeds are divided into qualified coated seeds and damaged coated seeds. The qualified coated seeds are shown in Fig. 3a, and the damaged coated seeds are shown in Fig. 3b.

Fig. 3 - The model of Red Clover Coated Seed

After coating, 100 red clover coated seeds were randomly selected as samples, and they were randomly placed on the shooting chassis, which contained three damaged coated seeds. The sample of image processing is shown in Fig. 4.

Fig. 4 - The sample of image processing

Image processing algorithm for qualified coated seeds

The effect of image preprocessing directly affects the recognition error of qualified coated seeds. In order to facilitate feature extraction and improve the accuracy of recognition, before extracting features, the captured images are subjected to ROI extraction, saturation adjustment, filtering, threshold segmentation, and morphological analysis. Finally, the contact area between the seeds is eliminated, so that each seed forms an independent individual for identification. In addition, based on the original image processing, advanced morphological analysis is used to retain qualified coated seeds, and broken coated seeds are eliminated to improve the accuracy of subsequent identification (*Meng, 2021*).

The image processing flow chart of qualified coated seeds is shown in Fig. 5.

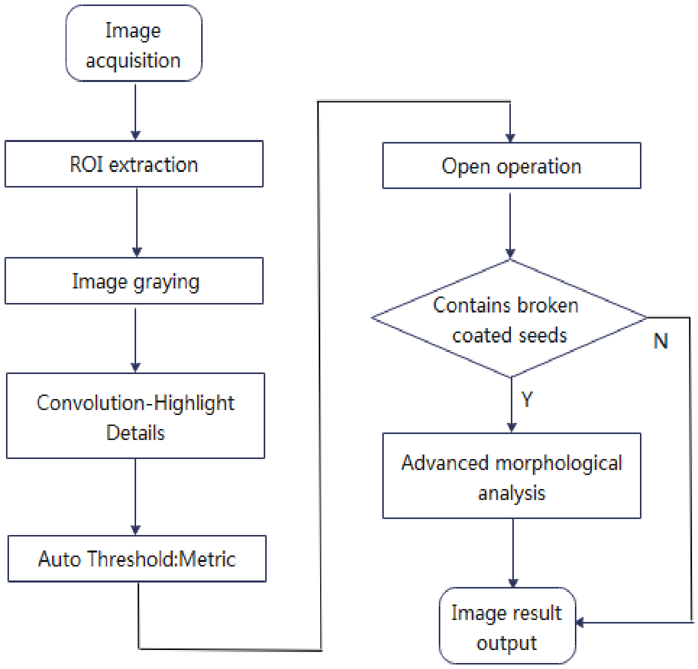

Fig. 5 - The image processing flow chart of qualified coated seeds

Image processing software is Vision Assistant 2018 developed by NI Company, which contains a complete set of image processing function library, which has rich and powerful functions, and can efficiently and quickly process images. Compared with other visual products, the software greatly simplifies the processing process and shortens the time of algorithm development and debugging.

The coated seeds are khaki. Considering that the background of the chassis is white, in order to better segment and highlight the contour of the seed, extract the color plane of the image, extract the saturation plane, and convert the image from color image to black and white image, which effectively removes background interference, highlight the outline of the seed, and facilitate subsequent processing. The gray-scale processing effect is shown in Fig. 6a.

Image shooting and processing are often contaminated by noise, and these noises will affect the visual effect of the image in the form of isolated pixels or pixel blocks. Noise is generally expressed as a large or small extreme value, which acts on the gray value of pixels in the image through addition and subtraction operations, causing bright or dark spot interference to the image. It not only affects the quality of captured images, but also affects the accuracy of seed feature recognition. Therefore, the use of convolution-highlight filter to highlight the details of the seed, make the image sharper, to solve the problem caused by noise. In the filtering process, the 3×3 square array is selected, and the type of the convolution kernel determines how the pixels in the image are transformed. In the calculation process, the convolution kernel slides point by point from the upper left corner to the lower right corner of the image, and each time it slides to a new pixel, the new value is obtained through the convolution operation, and the original pixel value of the image is overwritten. The pixel value corresponding to the central position of the template after convolution operation is P_5', with the following form:

$$P_5' = \sum_{i=1}^{9} WP_i = -P_1 - P_2 - P_3 - P_4 + 10P_5 - P_6 - P_7 - P_8 - P_9 \tag{1}$$

where: P_i -the pixel value, [-]; W -convolution kernel template, [-];

The design of image processing algorithm uses two convolutions highlight filtering, and the parameter settings are the same. The filtering effect is shown in Fig. 6b.

Automatic threshold segmentation method is a widely used segmentation technology. It can determine the gray threshold according to the gray histogram of the image, which has strong applicability. The image is divided into two categories: background and target. Those whose pixel gray values meet the uniformity distribution are classified into one category. The uniformity of pixel gray values is calculated to segment the image.

The principle of uniformity measurement is that if the initial threshold can divide the image into "background" and "target", then the distribution of gray values belonging to the same category should be uniform. Variance is used to measure uniformity. Let the gray value of any point in the original image be $f(x,y)$. The image to be segmented is divided into two categories: background C_1 and target C_2.

Given an initial threshold Th (in this paper, the initial threshold is set as the median), the width pixel value of the image to be segmented is represented by m, and the height pixel value is represented by n. The gray mean value μ_1 and within class variance value σ_1^2 corresponding to C_1 after segmentation are calculated respectively. The gray mean value μ_2 and within class variance value σ_2^2 corresponding to C_2 after segmentation are calculated respectively.

Both are calculated as follows:

$$\begin{cases} \mu_1 = \dfrac{1}{N_{C_1}} \sum\limits_{f(x,y)\in C_1} f(x,y) \\ \sigma_1^2 = \sum\limits_{f(x,y)\in C_1} \left(f(x,y)-\mu_1\right)^2 \end{cases} \tag{2}$$

$$\begin{cases} \mu_2 = \dfrac{1}{N_{C_2}} \sum\limits_{f(x,y)\in C_2} f(x,y) \\ \sigma_2^2 = \sum\limits_{f(x,y)\in C_2} \left(f(x,y)-\mu_2\right)^2 \end{cases} \tag{3}$$

where: N_{C_i} - the number of pixels in class i, [-];

The distribution probabilities p_1 and p_2 of the two types in the image are calculated respectively. The calculation formula of distribution probability is

$$\begin{cases} p_1 = \dfrac{C_{c1}}{m\times n} \\ p_2 = \dfrac{C_{c2}}{m\times n} \end{cases} \tag{4}$$

Substituting the distribution probability, gray mean value and intra-class variance corresponding to the background and the target, the optimal segmentation threshold Th^* which meet the conditions is Th.

The formula for calculating the optimal segmentation threshold is:

$$\left[p_1\sigma_1^2 + p_2\sigma_2^2\right]_{Th=Th^*} = \min\left\{p_1\sigma_1^2 + p_2\sigma_2^2\right\} \tag{5}$$

The image after thresholding has the problem of poor edge area segmentation of some seeds.

The threshold processing effect is shown in Fig. 6c.

Expansion and corrosion are not reciprocal operations, so they can be combined step by step. After thresholding, the binary image first erodes and then dilates, carries on the open operation to remove the unnecessary information in the image, such as noise, overlapping areas. After morphological processing, the coated seeds eliminate the contact between each other and become an independent particle, which improves the accuracy of the recognition algorithm. The particle refers to a group of connected non-zero or high gray pixels in the image.

The formula of erode objects operation is as follows:

$$P_0 = and(P_i) \tag{6}$$

where: P_o - center pixel, [-];

P_i - the pixels involved in the calculation in the image corresponding to the structural element, [-];

The dilate objects operation is as follows:

$$P_o = or(P_i) \tag{7}$$

After morphological processing, the coated seeds eliminate the contact area and are divided into independent individuals. The effect of morphological processing is shown in Fig. 6d.

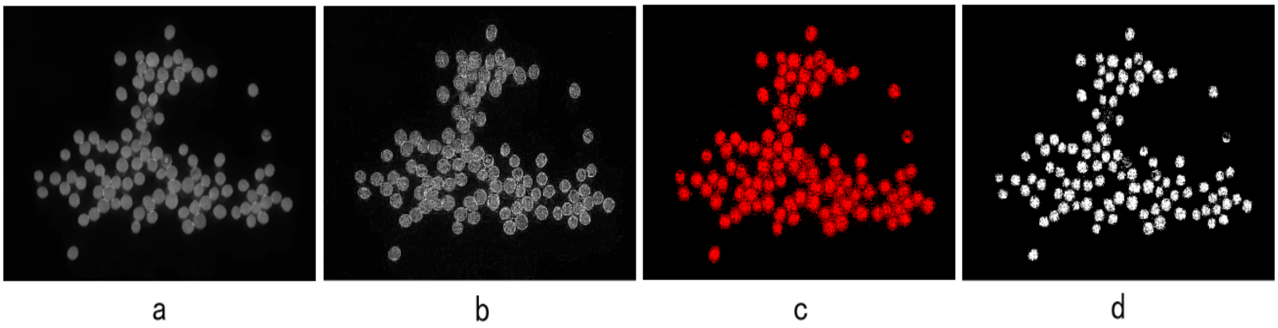

Fig. 6 - Image processing of qualified coated seeds

Advanced morphological processing algorithm is specially used for particle processing in binary image. The image processed by the algorithm is more suitable for quantitative analysis based on particle, extraction of target model and target recognition. The seed processed by the algorithm is a group of independent white pixels with high gray value. Through the pre-experiment, it is found that there is less powder on the surface of the damaged coated seeds, and the total value of white pixels after treatment is far less than the qualified coated seeds. Therefore, the operation of removing small objects in the advanced morphological algorithm can effectively remove the damaged coated seeds when the number of iterations is 3. The effect of advanced morphological processing is shown in Fig. 7.

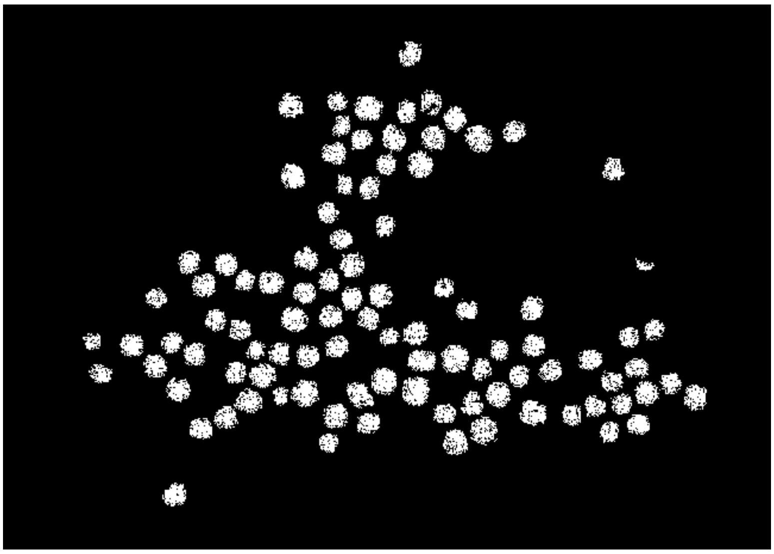

Fig. 7 - The effect of advanced morphological processing

Image processing algorithm for damaged coated seeds

A set of image processing algorithm was designed to identify the number of damaged coated seeds. Firstly, ROI extraction, saturation adjustment, Convolution-highlight Details filtering and Auto threshold segmentation are performed on the captured image. The preliminary process is similar to the algorithm of qualified coated seed map, and the threshold segmentation adopts the OTSU maximum between-class variance method. Secondly, the proper open operation and erode objects operation in morphological analysis are used to perform the close operation. Remove small objects operation in advanced morphological analysis is used to remove the interference in the image, and dilate objects is used to enhance the image effect. Finally, the qualified coated seeds are eliminated and the damaged coated seeds are retained for quantity identification.

The image processing flow chart of damaged coated seeds is shown in Fig. 8.

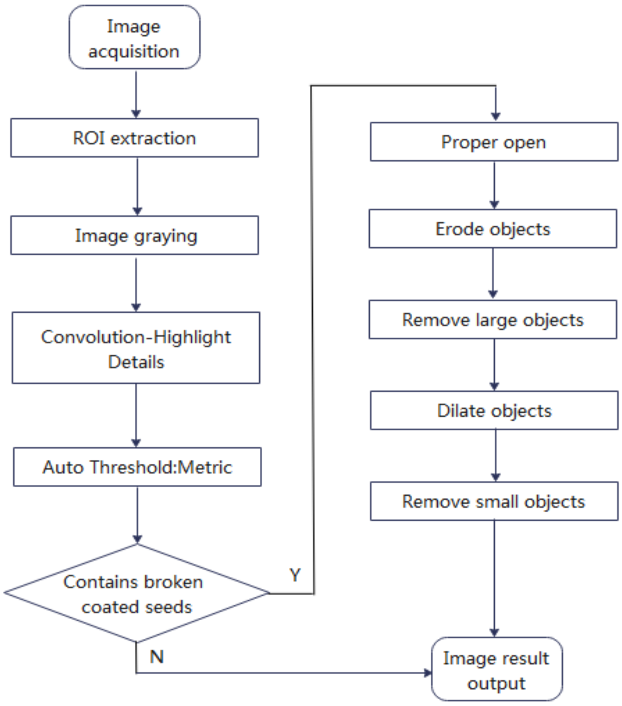

Fig. 8 - The image processing flow chart of damaged coated seeds

After image processing, the qualified coated seeds in the image can be effectively removed, and the damaged coated seeds can be retained. The image processing effect of damaged coated seeds is shown in Fig. 9.

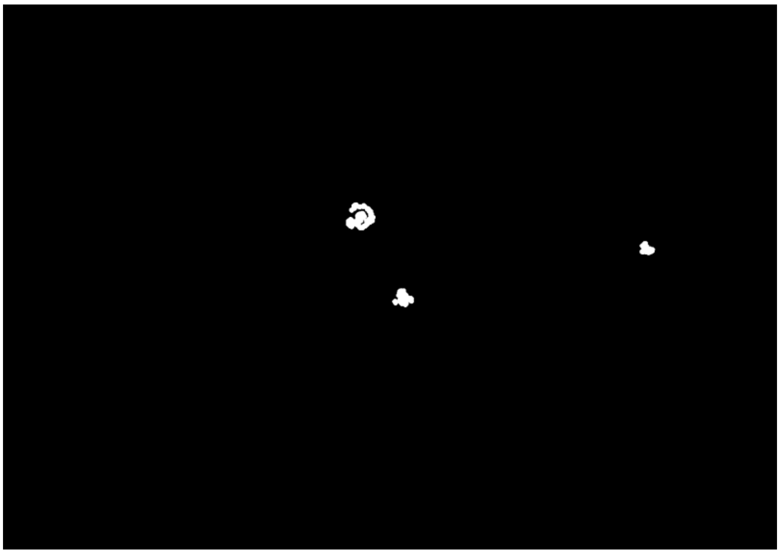

Fig. 9 - The image processing effect of damaged coated seeds

Identification control system

Using LabVIEW2018 to design a complete set of intelligent recognition system. The processed image is loaded into the Red Clover Seed intelligent recognition system for recognition. The modular design method is adopted, and each module is designed and written independently (*Bai, 2020*). The functional modules include parameter setting, image recognition, target marking and calculation processing. Initially the image path is selected, including the processed images of qualified coated seeds and the processed images of damaged coated seeds. Secondly, the appropriate threshold of the recognition function is determined through preliminary experiments. After the system runs, the identified image is generated, and the number of qualified coated seeds and the number of damaged coated seeds are obtained. Finally, the qualified rate of coating is obtained by calculation, and the results can be saved. The processing time of a single image is less than 1s. The intelligent recognition system of red clover coated seeds is shown in Fig. 10.

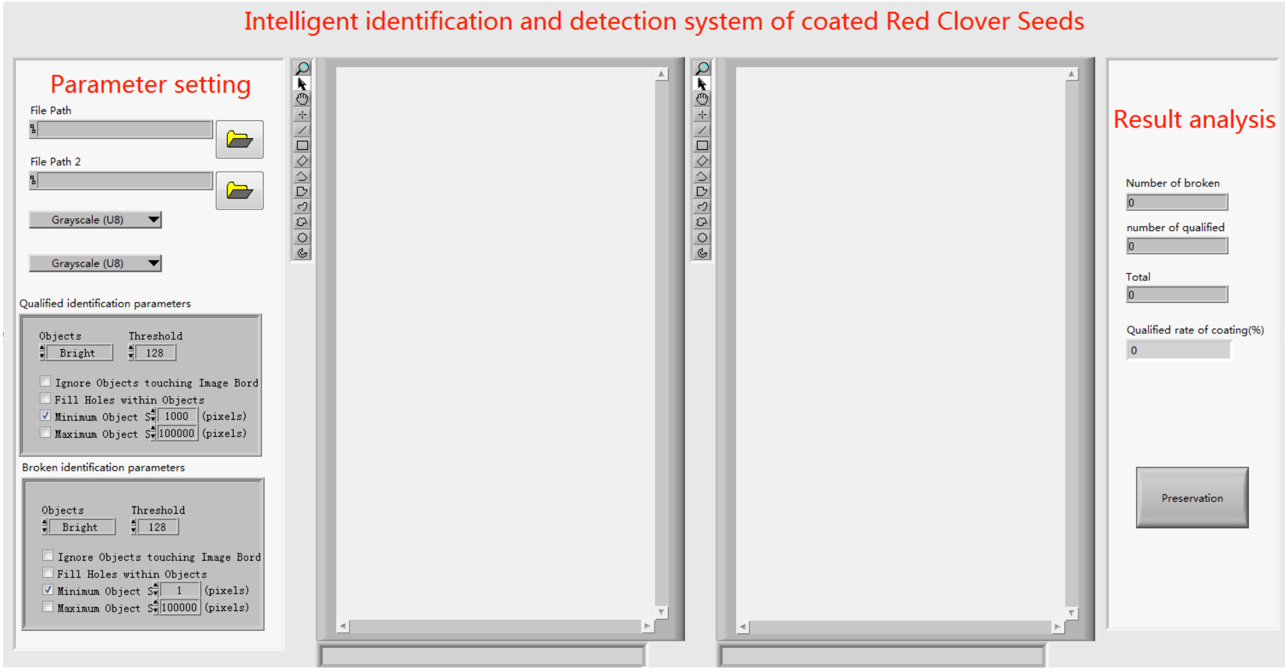

Fig. 10 - The intelligent recognition system of red clover coated seeds

The target seeds were identified by the identification function, and the number of two types of red clover coated seeds under a single group of coating parameters was obtained. Finally, the qualified coating rate was calculated. The system work flow chart is shown in Fig. 11.

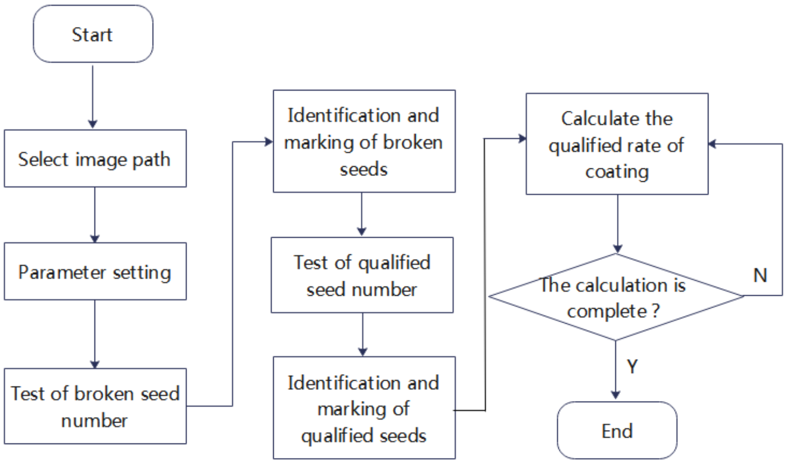

Fig. 11 - The system work flow chart

According to the total value of white pixels, the qualified number recognition algorithm uses the visual recognition function to recognize the white pixel target, sets the recognition threshold of the total number of pixels, identifies the coated seeds of the target in the image, and marks the number.

After advanced morphological analysis, the interference of small pixels is eliminated. When identifying the qualified number of coated seeds, because of the small error of the image processing algorithm of qualified coated seeds, some pixels of damaged coated seeds have not been removed. Therefore, the minimum total value of recognized pixels is adjusted to 1000, and all the targets with the total value of white pixels greater than 1000 in the image are identified by frame selection. Taking the sample image as an example, the total number of qualified coated seeds is 97. The recognition process is from the top to the bottom of the image, and the box is selected and numbered. The number starts from 0 and ends at 96, and the recognition success rate reaches 100%. The effect picture of qualified quantity identification is shown in Fig. 12.

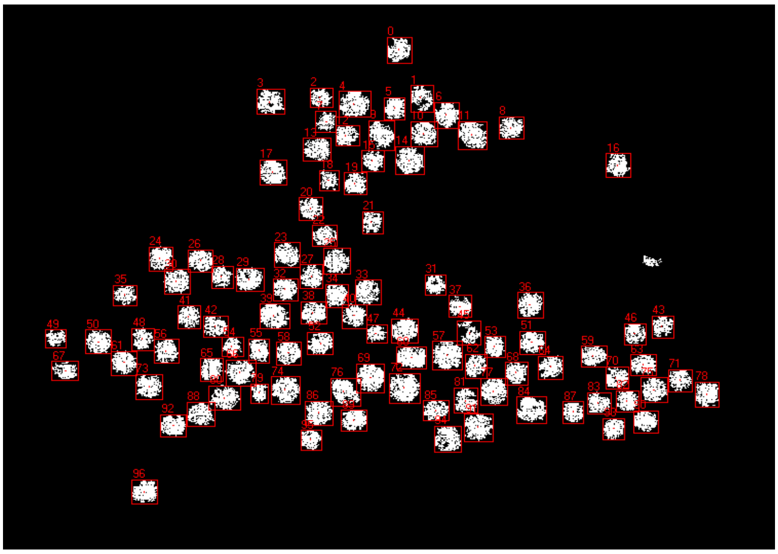

Fig. 12 - The effect picture of qualified quantity identification

The image processed by the image processing algorithm of damaged coated seeds is transmitted to the host computer in real time to identify the damaged coated seeds. Adjust the minimum total value of recognized pixels to 1, and recognize all the targets with white pixels in the image. Taking the sample image as an example, the number of damaged coated seeds is 3, and the recognition result is consistent with it. The effect picture of damage quantity identification is shown in Fig. 13.

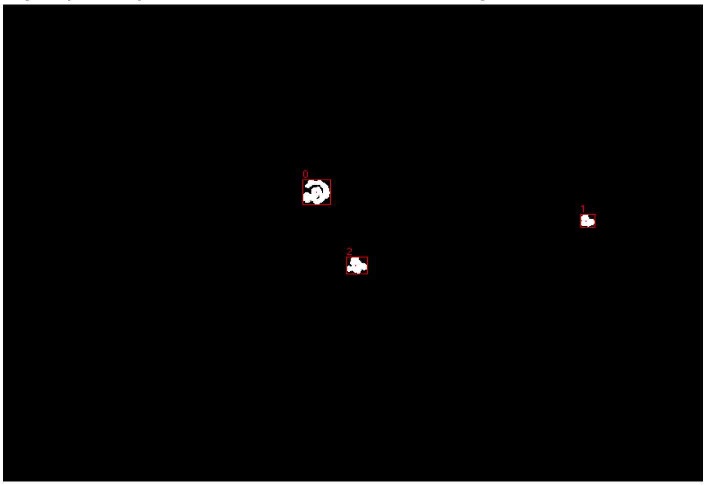

Fig. 13 - The effect picture of damage quantity identification

Before the system runs, the path of recognition image is initially selected, the recognition process is carried out at the same time, and the recognition results are displayed in real time. The total number of identification is equal to the number of qualified seeds plus the number of damaged seeds, and the qualified rate of coating is equal to the number of qualified seeds divided by the total number of identification. The generated results can be saved in Excel in real time to facilitate the comparative analysis of coating qualification rate of different coating parameters.

RESULTS AND DISCUSSIONS

Test and result analysis

In order to verify the stability and reliability of the device, a vibrating rotary coating machine was selected for test coating. The prototype of the device is shown in Fig. 14. Red clover seeds were used as the test sample to be coated, and then dried after coating (*Rogovskii I.L., 2020)*. The finished coated products are randomly selected and placed on the visual experiment platform for image shooting, followed by image processing and visual recognition. The experiment tests the reliability and accuracy of the coated seed recognition algorithm (*Wang, 2021*).

Fig. 14 - The prototype of the device

In order to verify the accuracy of the total number recognition algorithm and the seed recognition algorithm, a large number of coated products are randomly selected for the test. Considering that the optimal chassis capacity of the visual experiment platform is within 500, the number of test samples is 100 to 500, and the coated products are randomly selected to be placed on the chassis. The results are obtained by the traditional manual visual method and compared with the recognition results of the recognition system. Finally, the accuracy of identifying qualified coated seeds and multi-seed coated seeds was obtained. The test results are shown in Table 1.

Table 1

Experimental results of recognition algorithm

Total number of coated seeds	Number of qualified coated seeds	Number of damaged coated seeds	Detection of qualified coated seeds	Detection of damaged coated seeds	Detection accuracy of qualified coated seeds (%)	Detection accuracy of damaged coated seeds (%)
100	97	3	97	3	100.0	100.0
200	195	5	194	5	99.5	100.0
300	290	10	287	9	99.0	90.0
400	386	14	378	12	97.9	85.7
500	480	20	465	17	96.9	85.0

According to the data in Table 1, the accuracy rate of the identification system designed this time in detecting the number of qualified coated seeds reaches more than 96%. With the fewer seeds placed, the higher the accuracy. Due to the small number of damaged coated seeds, the identification error of damaged coated seeds is large. The experimental results show that the accuracy of detecting damaged coated seeds is more than 85%. As the number of identified seeds increases, the error increases relatively. Before shooting, the overlap can be reduced by gently moving to improve the recognition success rate and reduce the error. Experiments show that this method greatly improves work efficiency, reduces work intensity, and can effectively replace the traditional manual visual inspection method.

CONCLUSIONS

In this paper, through machine vision and image processing technology, an intelligent recognition and detection system of coated red clover seed is designed, including the visual experiment shooting platform and the upper computer detection system. Aiming at the red clover coated seeds, two unique image processing algorithms were designed to process the qualified coated seeds and damaged coated seeds respectively. The qualified number, damaged number and coating qualified rate were calculated by the upper computer detection system. A large number of experiments were carried out on the coated red clover seeds, and the following conclusions were drawn: the recognition accuracy of qualified coated seeds and damaged coated seeds were above 96% and 85% respectively, and the single image acquisition and processing time was about 1 s, which met the design requirements.

ACKNOWLEDGEMENTS

We acknowledge that this work was financially supported by Inner Mongolia natural science foundation project (2018MS05023) and National Natural Science Foundation of China (41661058).

REFERENCES

[1] Bai Y., Zhang C., Zeng L.., (2020), Design of photoacoustic microscope system based on LabVIEW platform. *MATEC Web of Conferences*, Vol 309, Issue4, pp. 4-16, China;

[2] Deng K., Liu Z., Deng J., Zhao Y., (2017), Variation of Surface Profile Topography Based on W-M Function Model. *Mechanical design and manufacturing*, Vol.1, Issue 1, pp. 47-50, China;

[3] Li Y., Wei C., Ding W., Yi Y., (2016), Study on the detection method of cleft glume hybrid rice seeds based on acoustic characteristics. *Transactions of the Chinese Society of Agricultural Machinery*, Vol 47, Issue 5, pp. 263-269, China;

[4] Meng F., Luo S., Sun H., Li M., (2021), Design and experiment of real-time detection and sorting device for corn seeds. *Transactions of the Chinese Society of Agricultural Machinery*, Vol 52, Issue3, pp. 153-159+177, China;

[5] Tamilselvi P., Manohar Jesudas D., (2016), A Study on Physical Properties of Pelleted Carrot (*Daucus carota.* L) Seeds. *Advances in Life Sciences*, Vol. 4, pp. 1220-1224, India;

[6] Rogovskii I.L., Titova L.L., Trokhaniak V.I., Marinina, L.I. Lavrinenko, O.T. Bannyi O.O.., (2020) Engineering management of machine for formation of artificial shell on seed vegetable cultures. *INMATEH - Agricultural Engineering*, Vol.61, Issue 2, pp. 165-174, Romania;

[7] Shao Z., Chen Z., Hou Z., Mi L., Qiu Y., (2018), Seed pelletizing movement characteristics of BYW-400 wheatgrass seed vibration pelletizing coating machine. *Transactions of the Chinese Society of Agricultural Engineering,* Vol.34, Issue 3, pp. 57-64, China;

[8] Sun Z., Li S., Yuan Y., (2017), Design and experiment of pelleting device for tomato seed coating. *Agricultural Mechanization Research*, Vol.39, Issue 6, pp. 162-169, China;

[9] Taylor A.G., Allen P.S., (2008), Bennett M. A. Seed enhancements. *Seed science research*, Vol.8, Issue 2, pp.245-246, USA;

[10] Xiong T., Lin Q., Feng X., (2019), Degradation dynamics of chlorfenapyr after pelleting and its control on Phyllotreta striolata. *Acta Entomologica Sinica*, Vol 56, Issue4, pp. 826-831, China;

[11] Xing J., Xu L., Ma S., Yuan Q., Chen C., Zeng J., Niu C., (2019), Development of laser orientation and embryo recognition device for horse-tooth shaped corn seed tip. *Transactions of the Chinese Society of Agricultural Engineering*, Vol.35, Issue 3, pp. 52-59, China;

[12] Zhu M., Chen H., Li Y., (2012), Retrospect and prospect of seed processing industry in China. *Transactions of the Chinese Society of Agricultural Engineering*, Vol 28, Issue2, pp. 1-6, China;

[13] Wang L., Hu C., He X., Guo W., Wang X., Hou S., (2021) A general modelling approach for coated cotton-seeds based on the discrete element method. *INMATEH - Agricultural Engineering*, Vol 63, Issue1, pp. 221 -230, Romania.