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Design and experiment of seed posture detection and adjustment device for garlic

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Abstract
In order to solve the problem of low orientation adjustment success rate and unsatisfactory orientation effect in garlic mechanical seeding, a garlic seed posture detection and adjustment device for garlic was designed. The device was developed to recognize garlic posture and control garlic posture through video acquisition, target detection and garlic directional motion control, which consisted of a posture adjustment system and an automatic control system. The posture adjustment device was designed to finish garlic bud orientation change, which consisted of a rotating plate, a shell, a conveyor pipe, a garlic funnel, a seed tube, and a fixed plate. The diameter of the conveyor pipe was determined based on the morphological parameters of the garlic seeds. Based on the mechanical analysis of garlic seeds in the conveyor pipe, the length and inclination of the conveyor pipe were determined. The automatic control system was designed to execute and control camera shooting, image processing and target detection, input action signal to the controller and receive feedback of action signal. The improved SSD algorithm was adopted to improve the identification accuracy of garlic posture detection. After the key components of the device were designed, the garlic seed posture detection and adjustment device test bench was built. The total time for garlic seed scale bud orientation detection, conveyance, and adjustment is 0.81 s. After adjustment, the upward rate of garlic buds was greater than or equal to 98.6%, and the orientation time of garlic buds adjustment was 0.5 s. The design of the device significantly improves the efficiency and accuracy of garlic seed orientation adjustment, which meets the requirements of garlic mechanical seeding.

Key words: garlic; pointed-end-up garlic planting; posture detection; adjustment.

Introduction
As a common condiment, garlic is an important economic crop in China (Qi *et al.*, 2022). Mechanized sowing of garlic can reduce labor intensity, improve production efficiency, reduce planting costs and increase income. Domestic and foreign scholars have carried out extensive

research on mechanized sowing of garlic (Benjaphragairat, 2010; Li *et al.*, 2017; Nare *et al.*, 2014; Guo *et al.*, 2021; Hou *et al.*, 2021; Li *et al.*, 2020). The posture of garlic in planting abroad is mainly lying flat, and the requirement for garlic posture is low (Bakhtiari and Loghavi *et al.*, 2009; Cui *et al.*, 2018; Zhang *et al.*, 2021; Im *et al.*, 2023; Song *et al.*, 2024), while upward orientation of garlic bulbs when planting has the advantages of high yield, good quality and high consistency of seedling emergence (Jin *et al.*, 2008). Domestic garlic planting is mainly based on upward posture of garlic bulbs. The special requirements of garlic planting posture increase the difficulty of garlic planting and limit the progress of garlic planting mechanization. Therefore, it is of great significance for the development of garlic industry to design a seed posture adjustment device to realize the posture adjustment of seeds when planting.

Some scholars have carried out research work on mechanical garlic bud posture adjustment and designed a mechanical mechanism to complete the garlic bud posture adjustment by using the physical and mechanical characteristics such as the center of gravity of the garlic seeds. Cui *et al*. (2022) designed an arc duck-billed garlic seed planter and carried out research on the working links of the planter such as single seed picking, bud direction control, and vertical planting, so as to better realize the adjustment of bud posture. Hou *et al*. (2018) designed a double duckbill garlic planter and adjusted the garlic bud posture by the upper and lower duckbill. Geng *et al*. (2018) designed a three-layer conical hopper, which used a three-layer hopper to make garlic seeds fall step by step to turn the bud posture. Xie *et al*. (2015) designed a sowing device based on the shape characteristics of garlic seeds, so that the seeds could meet the requirements of verticality after being buried. The adjustment of garlic seed posture by utilizing the physical and mechanical properties of the garlic seeds has a relatively good adjustment effect on garlic seeds with distinct features, but the adjustment effect on hybrid garlic seeds is not ideal (Geng *et al.*, 2020; Cheng *et al.*, 2023).

Some scholars have adopted automatic control technology to adjust the posture of garlic seeds and achieved certain results. Li *et al*. (2008), Zhao and Ma (2013), Yang (2010), Liu *et al*. (2022) and Wu *et al*. (2023) collected images of garlic seeds, respectively and identified bud tip or root of garlic seeds by image recognition. Based on capacitance detection technology, bilateral image recognition, deep learning and other technologies, Hou *et al.* (2020) realized garlic bud recognition and designed a garlic bud orientation adjustment device. The identification of bud orientation through image acquisition provides a new method for realizing the posture adjustment of garlic buds (Hou *et al.*, 2020; Li *et al.*, 2021; Hou *et al.*, 2023).

In this paper, the garlic bud posture adjustment was taken as the goal, and the garlic bud posture detection and adjustment device were designed. The research was conducted on image acquisition, bud recognition, bud posture adjustment to realize the accurate adjustment of garlic bud and provided reference for garlic mechanical planting.

Materials and Methods

Overall structure and working principle

The seed posture detection and adjustment device for garlic was mainly composed of a posture adjustment system and an automatic control system, as shown in Figure 1. The posture adjustment system consisted of a conveyor pipe, a seed tube, a garlic funnel, a fixed plate, a rotating plate and a shell. The rotating plate was driven by a stepper motor. The automatic control system consisted of CM35D-40 controller, industrial camera, power supply, stepper motor, TB6600 motor driver.

When the garlic seeds entered the conveyor pipe by the garlic funnel, the industrial camera detected the garlic seed posture (with the bud up or down) in real-time and made a judgment. When the garlic seeds entered the turning device through the transparent conveyor pipe, the buds facing up went directly down into the seed tube through the rotating plate inside the device, while the buds facing down enter the rotating plate and rotate 180° to adjust to the state of buds facing up before entering the seed tube, completing the orientation of garlic seeds. The device could identify three rows at the same time by one camera.

Design of the seed posture adjustment device

Design of conveyor pipe

When the garlic seeds entered the conveyor pipe, video acquisition and posture detection were carried out. The diameter of the pipe determined whether the garlic seeds could be transported normally, and the length and inclination of the conveyor pipe determined the conveying speed and time. Therefore, it was important to design the diameter, length and inclination of the conveyor pipe.

Determination of the conveyor diameter

The garlic seed was conveyed to the turning device through the transparent conveyor pipe, and the garlic seed in the conveyor pipe could only be in the state of bud facing up or bud facing down. Six typical garlic species, such as Jinxiang garlic, Lanling garlic and Yunnan garlic, were measured. The length of garlic seeds ranged from 28 mm to 40 mm, the width of garlic seeds ranged from 17 mm to 25 mm, and the thickness of garlic seeds ranged from 18mm to 25 mm. Therefore, the diameter of transparent conveyor pipe was determined to be 26 mm. In order to facilitate video capture, the conveyor pipe was made of transparent resin material.

Design of length and inclination angle of conveyor pipe

The length and inclination angle of the conveyor pipe have an important influence on the falling time of garlic seeds, and the working efficiency is improved as much as possible on the premise of ensuring clear image acquisition.

The forces acting on the garlic seed in the transparent conveyor pipe are shown in Figure 2.

The resultant force of garlic seed in the transparent conveyor pipe is:

$$\sum F = G_1 - \mathrm{f} = mg\sin\theta - \mu mg\cos\theta \qquad \text{(Eq. 1)}$$

At this time, the acceleration of garlic down along the inclined pipe is:

$$a = \frac{\sum F}{m} = \mathrm{g}\ (\sin\theta - \mu\cos\theta) \qquad \text{(Eq. 2)}$$

From $s = \frac{1}{2}at^2$, it can be obtained:

$$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2\times\frac{L}{\cos\theta}}{\mathrm{g}(\sin\theta - \mu\cos\theta)}} = \sqrt{\frac{2\mathrm{L}}{\mathrm{g}\cos\theta\ (\sin\theta - \tan\varphi\cos\theta)}} = \sqrt{\frac{2\mathrm{L}}{\mathrm{g}\cos\theta\frac{(\sin\theta\cos\varphi - \sin\varphi\cos\theta)}{\cos\varphi}}}$$

$$= \sqrt{\frac{2\mathrm{L}\cos\varphi}{\mathrm{g}\cos\theta\sin(\theta-\varphi)}} = \sqrt{\frac{2\mathrm{L}\cos\varphi}{\mathrm{g}\cos\theta\frac{1}{2}[\sin(2\theta-\varphi)-\sin\varphi]}}$$

$$= \sqrt{\frac{4L\cos\varphi}{g[\sin(2\theta-\varphi)-\sin\varphi]}} \qquad \text{(Eq. 3)}$$

Where φ=arctan (μ); *t,* sliding time of garlic (s); θ, slope angle of inclined pipe (°); *a*, the sliding acceleration of garlic seeds (m/s^2); g, gravitational acceleration (9.80 m/s^2); *L*, horizontal projection length of the pipeline (m); μ, friction coefficient of garlic seeds.

Determination of conveyor pipe color

In order to facilitate the image acquisition of garlic seeds, transparent resin material was used for conveyor pipe. In the experiment, it was found that the mechanism under the transparent inclined conveyor pipe was also collected into the image when the image was collected, which not only affected the recognition efficiency, but also affected the detection accuracy. In this study, different colors would be applied to the back of the conveyor pipe without affecting the camera's collection of garlic photos. Whether the different colors on the back of the conveyor pipe would affect the target detection efficiency and accuracy would be compared through experiments.

In this experiment, seven treatments of colorless, white, blue, black, green, yellow and red were selected, as shown in Figure 3. Lanling garlic was used for garlic seeds, and 10 experiments were carried out for each color. The test results were shown in Table 1.

As shown in Table 1, when the back color of the conveyor pipe was blue, the shortest time for target detection was 0.481s, and the recognition accuracy reached 100%. Therefore, the conveyor pipe with a blue back was adopted.

Design of turning device

The turning device was composed of a shell, a garlic bud rotating plate and a seed tube. The garlic bud rotating plate was the core mechanism to complete the orientation of garlic seeds, and the garlic bud rotating plate was driven by a motor. The working principle of the garlic bud rotating plate was shown in Figure 4.

When the garlic seeds entered the garlic bud rotating plate through the conveyor pipe, the garlic seeds with the bud facing up entered the hole and fell directly into the seed tube. When the garlic seeds with the bud facing down entered the blind hole of the garlic bud rotating plate, the control system controlled the rotating plate to rotate 180°, and garlic seeds were adjusted to the state of bud facing up and fell into the seed tube.

Design of automatic control system

The automatic control system included video acquisition module, target detection module and garlic-oriented action control module. The hardware composition was shown in Figure 5.

The main function of the system was to execute and control camera shooting, image processing and target detection, input action signal to the controller and receive feedback of action signal. The control core of the system was Jetson Nano, an edge computing processor with high performance. The controller received the signal conveyed by the Jetson Nano processor, converted the signal, and then transmitted it to the driver controlling the rotation axis of each stepper motor, and recorded the rotation angle and rotation time, then fed it back to the Jetson Nano processor. The system used CM35D-40 four-axis controller. The camera selected SONY IMX179 industrial camera with high resolution to comprehensively cover the multi-row garlic seed channel to capture garlic seed video.

The industrial camera was controlled by Jetson Nano to capture the video of garlic in the transparent conveyor tube, and continuously provided the source video for target detection. The object detection module detected the captured video through the object detection algorithm, and the folder where the image was located after detection provided instructions for controlling the garlic seed bud orientation adjustment device. The garlic-oriented action control module was used by the Jetson Nano processor to identify the image folder after detection, and provide action instructions to the PCA9685 chip and the CM-35D four-axis controller, which then controlled the rotation of the rotary drive motor to complete the garlic seed orientation. The workflow was shown in Figure 6.

Garlic seed posture recognition algorithm based on target detection technology

This system adopted SSD algorithm (Qin *et al.*, 2022; Su, 2022), took VGG16 as the basic model, and drew on DeepLab-LargeFOV to transform the fully connected layers fc6 and fc7 of VGG16 into convolution layers conv6 and conv7. At the same time, the pool layer pool5 was changed from the original stride=2 to stride=1 3*3. Correspondingly, an Atrous Algorithm was adopted, that was, conv6 used extended convolution or perforated convolution. Without increasing the complexity of the parameters and the model, the convolution field of view was expanded exponentially, and the expansion rate (dilation rate) parameter was used to represent the expansion size (Figure 7) i) was an ordinary 3*3 convolution, the filed of view was 3*3; ii) was the expansion rate of 2, the field of view became 7*7; iii) represented when the expansion rate was four, the field of view was expanded to 15*15, but the characteristics of the field of view were more sparse (Yao, 2022). Conv6 used an extended convolution of 3*3 size, but dilation rate=6.

After determining the training samples, the loss function needed to be determined, which was defined as the weighted sum of localization loss (loc) and confidence loss (conf):

$$L(x, c, l, g) = \frac{1}{N}(L_{conf}(x, c) + \alpha L_{loc}(x, l, g)) \quad \text{(Eq. 4)}$$

Where: N is the number of positive samples of the prior box. Here, $xp\ ij \in \{1, 0\}$ was an indicator parameter, when $xp\ ij$=1, the i th prior box matched the j th garlic seed, and the garlic seed category was p; c was the predictive value of category confidence ; l was the position prediction value of the corresponding bounding box of the priori box, and g was the position parameter of the garlic seed. For position errors, Smooth_{L1} loss was used, defined as follows:

$$L_{loc}(x, l, g) = \sum_{i \in Pos}^{N} \sum_{m \in \{cx, cy, w, h\}} x_{ij}^{k} \text{smooth}_{L_1}(l_i^m - \hat{g}_j^m) \quad \text{(Eq. 5)}$$

$$\hat{g}_j^{cx} = (g_j^{cx} - d_i^{cx}) / d_i^{w} \quad \hat{g}_j^{cy} = (g_j^{cy} - d_i^{cy}) / d_i^{h} \quad \hat{g}_j^{w} = \log\left(\frac{g_j^{w}}{d_i^{w}}\right) \quad \hat{g}_j^{h} = \log\left(\frac{g_j^{h}}{d_i^{h}}\right)$$

$$\text{smooth}_{L_1}(x) = \begin{cases} 0.5x^2 & \text{if} |x| < 1 \\ |x| - 0.5 & \text{otherwise} \end{cases} \quad \text{(Eq. 6)}$$

Because of the existence of xp ij, the position error was calculated only for positive samples. The g of garlic seed was encoded to obtain $\hat{g}$. If variance_encoded_in_target=True was set, variance should be added to the encoding:

$$\hat{g}_j^{cx} = (g_j^{cx} - d_i^{cx}) / d_i^{w} / \text{variance}[0] \quad \text{(Eq. 7)}$$

$$\hat{g}_i^{cy} = (g_j^{cy} - d_i^{cy}) / d_i^{h} / \text{variance}[1] \quad \text{(Eq. 8)}$$

$$\hat{g}_j^{w} = \log (g_j^{w} / d_i^{w}) / \text{variance}[2] \quad \text{(Eq. 9)}$$

$$\hat{g}_j^{h} = \log (g_j^{h} / d_i^{h}) / \text{variance}[3] \quad \text{(Eq. 10)}$$

The weight coefficient α was set to 1 by cross validation. Eqs. 4 through 10 are derived from the Chinese Software Developer Network (https://blog.csdn.net/qq_41368247/article/details/88027340).

Control design of CM-35D four-axis controller

The controller needs to connect three motor drives. The stepper motor has two rotation instructions A and B. The A instruction performs the action when the garlic bud is upward, and the B instruction performs the action when the garlic bud is downward. In order to ensure that

three rows of garlic seeds are transported to the next seed tube at the same time, the system control instructions are shown in Table 2.
It can be seen from Table 2 that the time length of the garlic seed control turnaround and reset is 0.5 s.

Determination of other parameters
In order to improve the detection efficiency, the garlic seed posture detection experiment was carried out. The results showed that when the installation distance between the camera and the transparent conveyor pipe was 15cm, the back color of the conveyor pipe was blue, equipped with a light shield and illuminated by LED lights, and the camera resolution was 1600*1200, the recognition of garlic seed posture was the best. The garlic posture recognition time was 0.31 s.
The inclination angle of the transparent conveyor pipe has an important influence on the conveying efficiency and video clarity. Considering comprehensively, the inclination angle θ of the transparent conveying pipe was 35°.
By substituting t=0.31 and θ=35° into formula (3), L= 17.90 cm was obtained, that was, the length of transparent conveyor pipe was 17.90 cm+4 cm (garlic seed length), that was 21.9 cm. The aforementioned design is intended to achieve automated control of garlic clove orientation during sowing, ensuring that the scaly bud faces upward.

Results and Discussion
Six species of garlic seeds with large scale planting in China were selected as samples: Lanling garlic seeds, Jinxiang garlic seeds, Kaiyuan garlic seeds, Baodi garlic seeds, Sheyang garlic seeds and Yunnan purple garlic seeds; 50 garlic seeds were randomly selected for bud orientation adjusting test.
After designing the size and structure of the key components of the test bench, a high-precision and high-quality 3D printer (printing material was transparent resin and imported 5400 material) was selected to print the key components. When the printing was completed, it was assembled with the aluminum alloy frame, and tested on the self-built multi-rows garlic bud adjustment device test bench that relied on target detection. The garlic seed posture detection and adjustment device test bench were shown in Figure 8. The test results were shown in Table 3.
In this system, garlic posture recognition and garlic bud orientation adjustment could be carried out simultaneously, and the operation of the system was shown in Figure 9. The yellow rectangle represented the garlic seed transportation time, and the blue rectangle represented the garlic seed posture mechanical adjustment and system reset time. The total time of the first operation of the device was 0.81 s, and each subsequent operation was 0.5 s.

Conclusions
A new type of multi-row seed posture detection and adjustment device for garlic was designed. There were only two postures of garlic seeds in the whole device, which was upward or downward. By cooperating with the intelligent control system of the device, garlic seeds could be adjusted to upward. A camera could identify three rows at the same time, which met the requirements of bud upward planting of garlic seeds.
The target detection module of this system was completed with the help of SSD algorithm, and the process was optimized on this basis. In the experiment, the database of garlic seeds pictures was expanded to make this algorithm meet the requirements of this design.
The garlic seed posture detection and adjustment device test bench were built, and the performance test of the whole system was carried out. The results showed that after adjustment the upward rate of garlic buds was≥ 98.6 % , and the orientation time of garlic buds adjustment was 0.5 s. The upward rate of garlic buds and orientation adjustment efficiency were significant.

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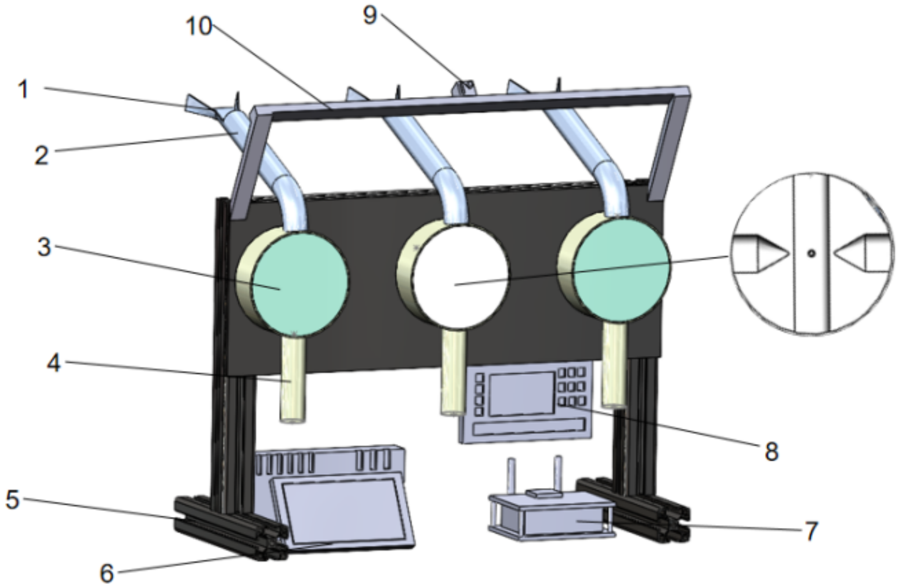

Figure 1. Structure diagram of seed posture detection and adjustment device for garlic. 1, Garlic funnel; 2, transparent conveyor pipe; 3, turning device; 4, seed tube; 5, frame; 6, electronic screen; 7, Jetson Nano; 8, CM-35D controller; 9, industrial camera; 10, camera mount.

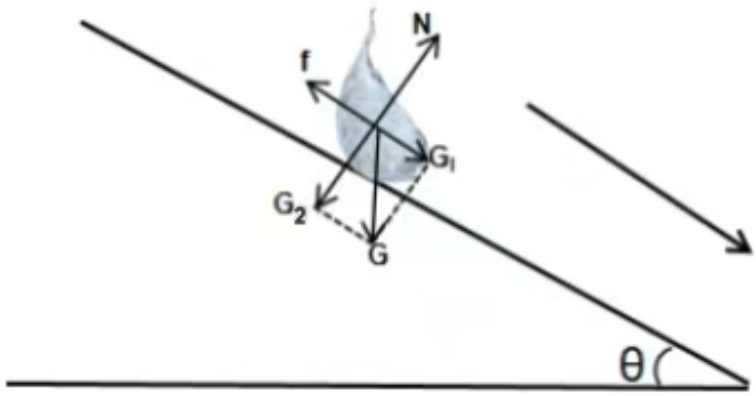

Figure 2. Force analysis of garlic seed in conveyor pipe. N is the support force exerted on the garlic seed, N; G is gravity acting on the garlic seed, N; G_1 is component force of gravity acting on the garlic seed along the direction of the inclined surface, N; G_g is gravity acting on the garlic seed perpendicular to the inclined plane, N; f is the friction of the garlic seed.

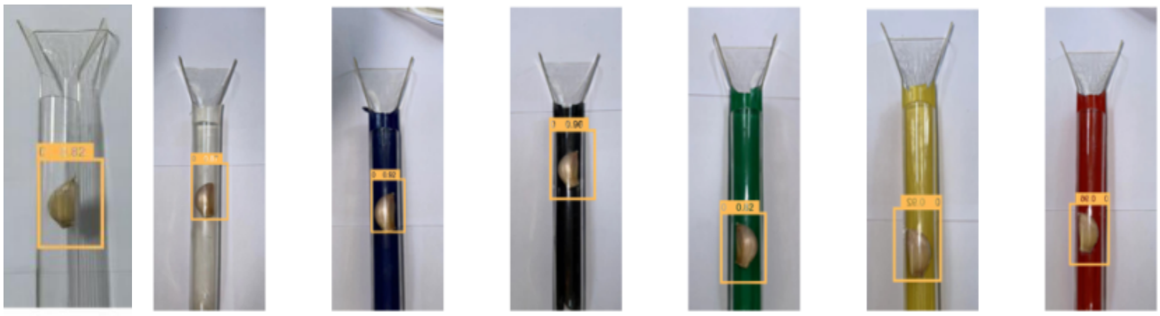

Figure 3. Differential contrast of the recognition boxes under different colors.

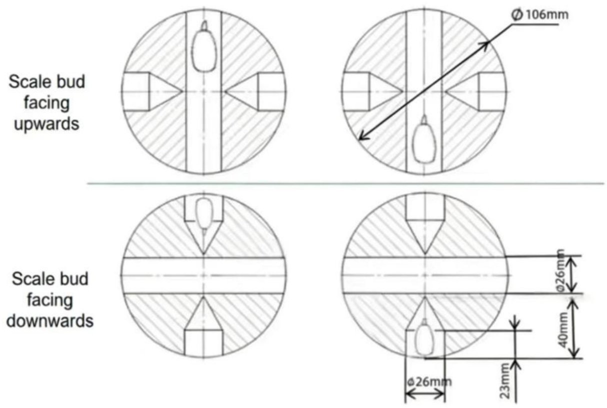

Figure 4. Working principle of garlic bud rotating plate.

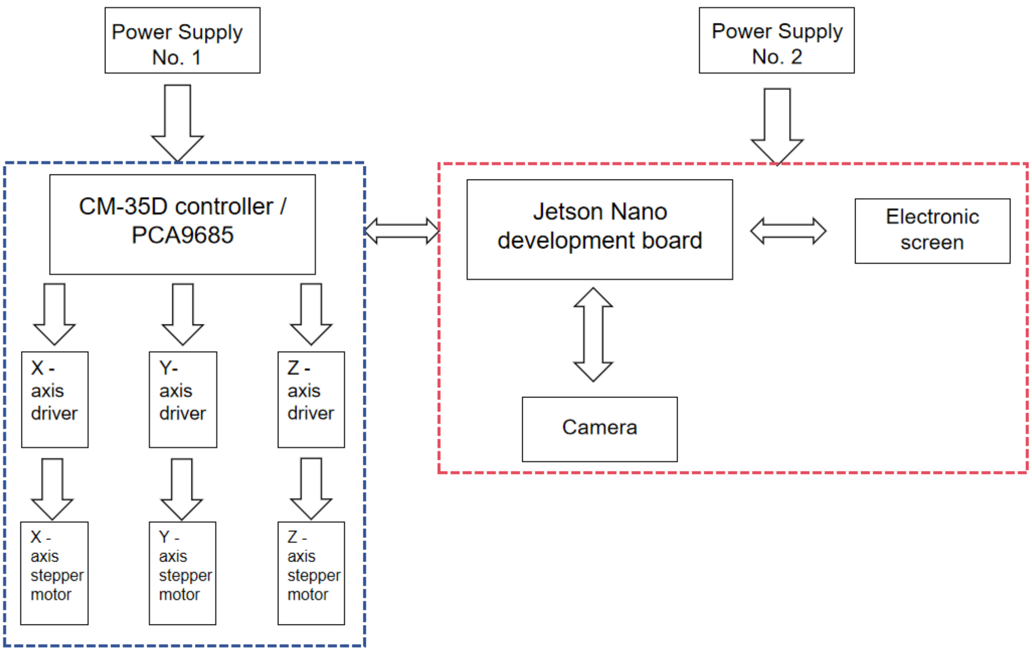

Figure 5. Structure diagram of hardware system.

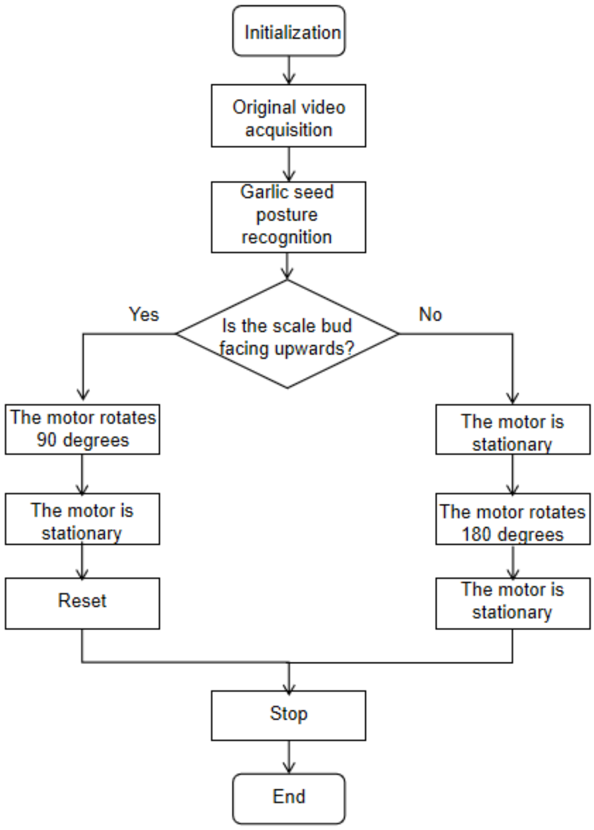

Figure 6. System control flow chart.

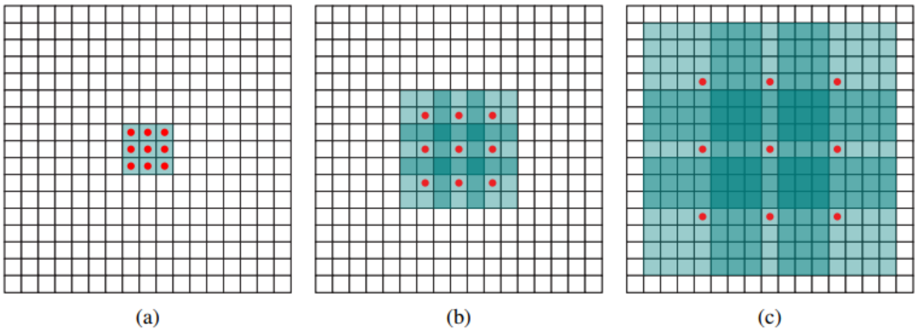

Figure 7. Extended convolution.

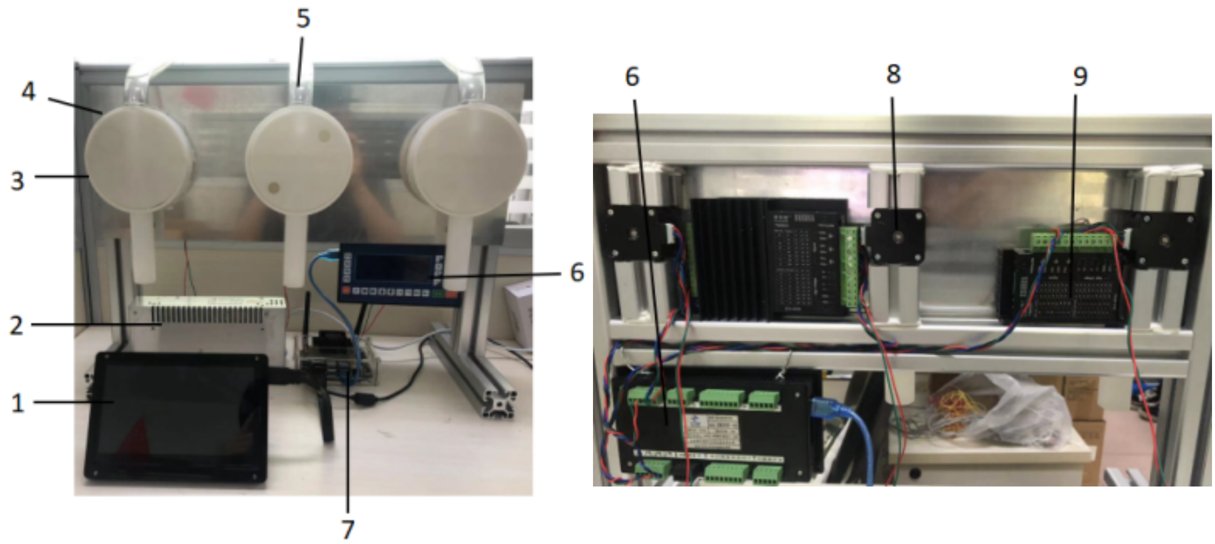

Figure 8. Experiment table of seed posture detection and adjustment device for garlic. 1, Display screen; 2, power supply; 3, turning device; 4, shell; 5, transparent conveyor pipe; 6, CM35D-40 controller; 7, Jetson Nano; 8, 42 stepper motor; 9, stepper motor controller.

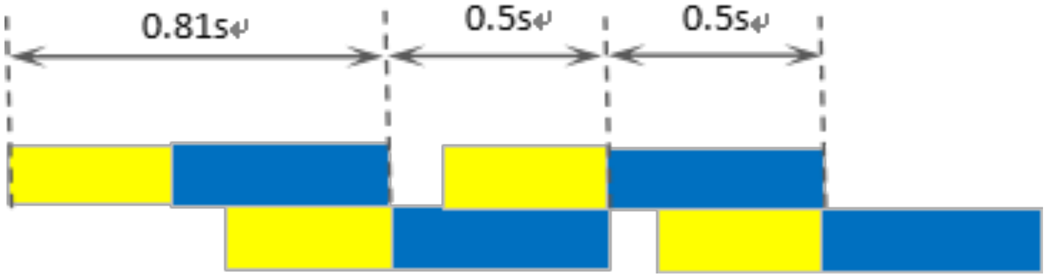

Figure 9. Time of garlic seed orientation.

Table 1. Different color identification test and test results.

Color	Recognition accuracy rate/%	Average identification time/s
Colorless	98.6	0.512
White	100	0.502
Blue	100	0.481
Black	100	0.496
Green	100	0.493
Yellow	100	0.507
Red	100	0.493

Table 2. System control instruction flow sheet.

	Instruction A	Instruction B
Action 1	Clockwise rotation 90° (0.1 s)	Static 0.2 s
Action 2	Static 0.3 s	Clockwise rotation 180° (0.1 s)
Action 3	Clockwise rotation 90° (0.1 s) (Reset)	Static 0.2 s
Action 4	Finish	Finish

Table 3. Test results.

Garlic seed posture	Parameter	Value
Bud upward	Recognition success rate	100%
	Orientation success rate	100%
	Recognition time	0.29 s
	Conveying time	0.31 s
	Mechanical adjustment time	0.4 s
	Reset time	0.1 s
Bud downward	Recognition success rate	98.6%
	Orientation success rate	98.6%
	Recognition time	0.31 s
	Conveying time	0.31 s
	Mechanical adjustment time	0.5 s
	Reset time	0 s