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Optimal design of garlic clove's orientation adjustment system based on parallel robot

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Abstract: The upward seeding of garlic cloves has the characteristics of emergence early and strong, which is the common planting agronomy of garlic in China. Based on the parallel robot, a control system of garlic clove's orientation was designed to improve the upward seeding rate, and to promote the garlic planting mechanization in China. This system mainly included four modules: image acquisition, image preprocessing, garlic clove feature extraction and instruction drive. First, when the garlic cloves were transported to the established position, the visual system received the photo trigger signal emitted by the parallel robot and collected the image immediately. Second, the ideal binary image was obtained by median filtering, binarization, and morphological processing of the image to fill holes and filter out background particles, and the area of the connected domain of the binary image was screened according to the size range of garlic species to obtain the garlic binary image of the right size. Third, the center contour of the image and the curvature of the contour were extracted and calculated, and the part with the maximum curvature was regarded as the bud of the garlic clove and this part was used as the clove orientation, while this orientation would be quantified as the angle value and sent to the robot. Finally, according to the position information, velocity vector information and orientation information of the garlic cloves, the parallel robot controlled the grasper to grasp the garlic clove, and the garlic clove was adjusted to a unified direction and put into the established position, so as to adjust the orientation of the garlic clove. The key parameters of the adjusting system were tested and the multiple regression model of the adjusted success rate was established. The results indicated that: (1) the indicators of adjusted success rate were impacted by weight of garlic clove, conveying speed and grasping period significantly. (2)the order of priority of influencing factors is grasping time, weight of garlic cloves, and conveying speed. (3) the combination of the weight of garlic seed (4.54 g), the conveying speed (0.1 m/s), and the grasping time(2.445 s) led to a relatively high adjusted success rate (97.41%). This study provided a technological guidance for the application of the intelligent garlic clove's orientation control system, which will be helpful for solving the problem of using an embedded industrial computer to adjust garlic clove's orientation, and promoting the garlic planting mechanization in China.

Keywords: parallel robot; upward seeding; control system; orientation adjustment; visual system

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0 Introduction

China is the world's largest garlic producer, consumer and exporter. The cultivated area of China is about 50% of the world's total, and its annual output and exports are about 80% of the world's total[1-3].

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However, the mechanized seeding rate of garlic in China is less than 5%, and artificial cultivation is the main method at present, which leads to high labor intensity and low operation efficiency. Therefore, it is of great practical significance to realize mechanized planting of garlic in China.

Upward seeding of garlic cloves has the characteristics of emergence, early and strong, which is the common planting agronomy in China[4-6]. The degree of mechanization of garlic cultivation in Occident is quite high[7-10], but they does not have the requirement for the clove's orientation, which is difficult to adapt to the agronomic requirements of China[11-12]. In order to realize the upward seeding of the garlic, Japan and South Korea garlic utilize some structural components to extrude the bud of the garlic clove while the buds of the garlic clove of the main varieties in China are not prominent, so that the adaptability and application of the technology is poor in China. The garlic clove's orientation adjustment technology is the core technical bottleneck to the development of garlic cultivation in China, so it is urgent to be researched and solved[13-15].

In this study, we proposed a kind of garlic clove's orientation control technology based on the parallel robot and embedded industrial computer. The technology could recognize the identification, positioning and adjustment of garlic cloves by using visual system, four degree of freedom manipulator and pneumatic claw, and we conducted the optimization design for the main factors of the indicators of adjusted success rate, which will be helpful for solving the garlic clove's orientation adjustment, and breaking through the core technical bottleneck of garlic planter in China.

1　Garlic clove's orientation adjustment system

1.1　Structure and working principle

The structure diagram is shown in Figure 1. The parallel robot mainly made up of control cabinet, body, speed control motor and flexible touch grasper, and the model was D3PM-600-P0. The working diameter of the parallel robot was 600 mm, and the maximum load was 3 kg. The visual system was mainly composed of an industrial computer (P15RF), LED light belts, industrial camera (MV-CE020-10GC) and black boxes. And the model of camera lens was Computar MP2-8.

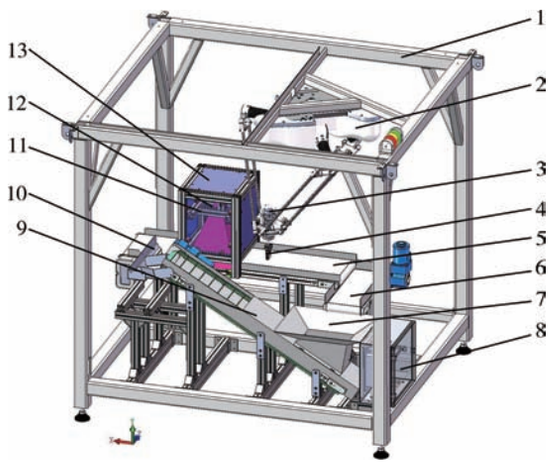


Figure 1　Structural representation of garlic clove's orientation adjustment system

1. Frame　2. Robot body and manipulator　3. Speed control motor　4. Grasper　5. First conveyor　6. Second conveyor　7. Hopper　8. Control cabinet　9. Hoist　10. Vibration conveyor　11. LED belt　12. Camera　13. Black box

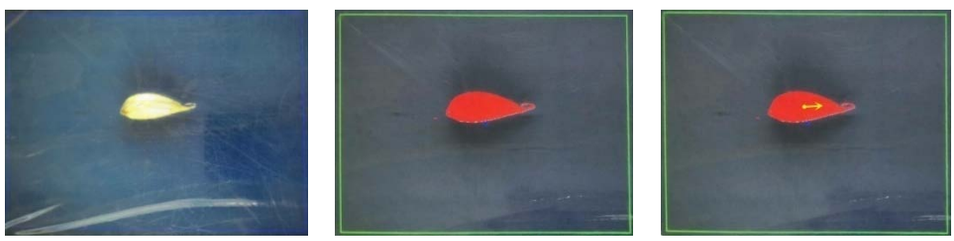
The garlic cloves were put into the hopper, and they were dropped into the vibration conveyor through the hoist. After the vibration, the cloves were dropped into the first conveyor in an independent state. A visual system was installed above the first conveyor. When cloves were passing through it, the visual system determined the position and orientation images by photography of camera, and sent the images to the parallel robot controller. Under the assistance of the speed sensor and the orientation information received, the controller adjusted the clamping direction of the grasper through the speed regulating motor, and the garlic clove was grasped through the robot body and the manipulator. Finally, the clove orientation was adjusted to a unified direction and put into the established position. The unfinished garlic cloves were returned to the hopper through the second conveyor.

The four operation steps were as follows: (1) setting the angle, position and grasping time of the grasper; (2) performing the grasp action; (3) adjusting the angle of the grasper; (4) putting garlic clove in the set position.

1.2　Visual system and garlic clove's orientation adjustments

The visual program mainly consisted of four

modules: image acquisition, image preprocessing, clove feature extraction and instruction drive. The four modules were executed sequentially in the while process to accomplish the function of image acquisition, preprocessing, garlic feature judgment and issuing instructions to the controller[16-20]. Figure 2 shows the three main working steps after the program starts. First, the visual system received the photo trigger signal emitted by the parallel robot and collects the image. Second, the ideal binary image was obtained by median filtering, binarization, and morphological processing of the image to fill holes and filter out background particles, and the area of the connected domain of the binary image was screened according to the size range of garlic species to obtain the garlic binary image of the right size. Third, the center contour of the image and the curvature of the contour were extracted and calculated, and the part with the maximum curvature was regarded as the bud of the clove and this part was used as the clove orientation, while this orientation would be quantified as the angle value and sent to the robot.



(a) Collect image (b) Obtained ideal binary image and screen connected domain (c) Extract and calculate the clove's center and orientation

Figure 2 Three main working steps of visual program

2 Optimal experiment

2.1 Experimental design

In order to conduct the algorithm verification test, we chose more than 10 kg garlic cloves and classified them by weight. All the garlic cloves were selected randomly for image acquisition without reuse. Two hundred images of single garlic clove and 200 images of multiple garlic cloves were collected, respectively, with BMP format. The whole test process was completed on the parallel robot machine.

The previous tests showed that the weight of garlic clove, conveying speed and grasping time had the significant influence on the adjusted success rate. Therefore, these three factors were taken as the experimental factors, and the adjusted success rate was taken as the experimental response index. The experimental design was based on Box-Benhnken central composite design theory, and the experimental factors, their levels, and their coded values are listed in Table 1.

The formula for calculating the adjusted success rate is shown in Formula 1.

$$Y_1 = \frac{N_1}{N_0} \times 100\% \tag{1}$$

where, Y_1 is the adjusted success rate, %; N_1 is the weight of garlic cloves which were successfully adjusted, g; N_0 is the total weight of garlic cloves, g.

Table 1 Parameters and coded results of X_1, X_2, and X_3

Levels	Weight of garlic clove X_1/g	Conveying speed X_2/(m·s^{-1})	Grasping time X_3/s
−1	3	0.10	2.5
0	5	0.15	2
1	7	0.20	1.5

2.2 Results and analysis

The adjustment experiments of garlic clove orientation are shown in Figure 3.

The experiment design and results were shown in Table 2.

According to the multiple regression fitting analysis, the regression equation of Y_1 can be written as:

$$Y_1 = (93.2 - 3.25X_1 - 2.375X_2 - 5.125X_3 - 0.25X_2X_3 - 6.975X_1^2 - 0.725X_2^2 - 2.725X_3^2) \times 100\% \tag{2}$$

The significant variables from the results of the statistical analysis of the adjusted success rate based on the optimization numerical module of Design-Expert software are listed in Table 3.

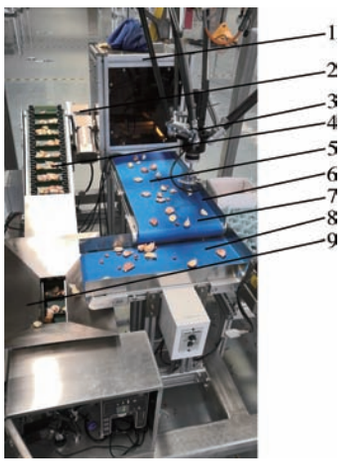


Figure 3　Adjustment experiments of garlic clove orientation

1. Visual system　2. Vibration conveyor　3. Grasper　4. Hoist　5. Garlic clove before adjustment　6. Garlic clove after adjustment　7. First conveyor　8. Second conveyor　9. Hopper

Table 2　Experiment design and results

No.	X_1	X_2	X_3	Y_1/%
1	−1	−1	0	88
2	1	−1	0	87
3	−1	1	0	85
4	1	1	0	78
5	−1	0	−1	93
6	1	0	−1	89
7	−1	0	1	83
8	1	0	1	76
9	0	−1	−1	98
10	0	1	−1	94
11	0	−1	1	84

Note: X_1、X_2 and X_3 represent the coding value of each factor.

The optimal parameter combination of Y_1 was weight of garlic clove (4.54 g), the conveying speed (0.1 m/s), and grasping time(2.445 s). At this stage, the adjusted success ratepredicted by the model was 97.41%. Under the same experimental conditions, three batches were tested, and 1 000 cloves were grabbed in each batch. The average success rate of adjustment was 96.67%. The regression model of the adjusted success rate was consistent with the experimental results.

Table 3　Variance analysis of regression models

Source	Y_1				
	Sum of squares	df	Mean square	F value	p-value
Model	591.979 4	9	65.775 49	13.723 65	0.0011**
X_1	84.5	1	84.5	17.630 4	0.0040**
X_2	45.125	1	45.125	9.415 052	0.018 1*
X_3	210.125	1	210.125	43.841 28	0.0003**
X_1X_2	−1.1E−13	1	−1.1E−13	−2.4E−14	1.000 0
X_1X_3	−1.1E−13	1	−1.1E−13	−2.4E−14	1.000 0
X_2X_3	0.25	1	0.25	0.052 161	0.825 9
X_1^2	204.844 7	1	204.844 7	42.739 59	0.0003**
X_2^2	2.213 158	1	2.213 158	0.461 762	0.518 6
X_3^2	31.265 79	1	31.265 79	6.523 414	0.037 9*
Residual	33.55	7	4.792 857		
Lack of fit	16.75	3	5.583 333	1.329 365	0.382 3
Pure error	16.8	4	4.2		
Cor total	625.5294	16			

Note: $P<0.01$(highsignificant,**), $P<0.05$(significant,*).

3　Conclusions and discussions

3.1　Conclusions

First, based on machine vision, we designed a garlic clove's orientation adjustment device. The industrial camera was used to collect the image of garlic seeds, while the clove orientation was identified by image analysis. According to the recognition results, the clove orientation was adjusted to appropriate direction.

Second, an algorithm for garlic clove orientation recognition was proposed. The garlic binary image was obtained by image preprocessing, and the parallel robot found the garlic connected region which was calculated and analyzed to acquire the characteristic parameters of the bud of the garlic clove, and the characteristic parameters was used to recognize the garlic clove orientation.

Third, three-factors and three-levels regression orthogonal test was carried out by Box-Behnken central composite method to establish a multiple regression model for the adjusted success rate. The combination of the weight of garlic seed (4.54 g), the conveying speed (0.1 m/s), and the grasping time(2.445 s) led to a

relatively high adjusted success rate (97.41%), and the result of the tests was 96.67%.

3.2 Discussions

Some garlic cloves happened to have an outwardly protruding slender bulge which was similar to the buds, and led to the error of algorithm identification, which indicated that identification algorithms need to be improved in the later research.

The recognition algorithm had poor filtering effect on accidental interference factors (eg. garlic peel), and could not recognized the garlic cloves without peel well, which reduced the adjusted success rate.

The probability of abnormal factors occurring at the same time was low, so the adjusted success rate was high for garlic clove's orientation by using the proposed algorithm.

References

[1] FAO. Crop queries of production volume of data [EB/OL]. http://www.fao.org/faostat/, 2022-04-20.

[2] MANJUNATHA M, SAMUEL D V K, ANURAG R K, et al. Development and performance evaluation of a garlic peeler [J]. Journal of Food Science and Technology, 2014, 51: 3083-3093.

[3] FENG J. Research on export market environment of Chinese garlic enterprises based on export income instability [D]. Wuhan: Huazhong Agricultural University, 2014.

[4] ZHANG H, YANG F R, YUN Y Z. High yield cultivation techniques of garlic [J]. Modern Agriculture, 2018(3): 4-5.

[5] ZHANG H Y, MENG L, WANG X M, et al. High quality and high yield cultivation techniques of film garlic in Xuzhou area [J]. Vegetables, 2016(10): 41-43.

[6] BOWERS S A, HAYDEN C W. Influence of seed orientation on bean seedling emergence [J]. Agronomy Journal, 1972, 64(6): 736-738.

[7] HU L L, HU Z C, WU F, et al. Domestic garlic planting and production machinery [J]. Jiangsu Agricultural Science, 2010(6): 576-578.

[8] HU Z C, WANG H O, WU F, et al. Summary of mechanized cultivation and processing of garlic in America [J]. Journal of Anhui Agricultural Sciences, 2007, 35(13): 4059-4061.

[9] BAKHTIARI M R, LOGHAVI M. Development and evaluation of an innovative garlic clove precision planter [J]. Journal of Agricultural Science and Technology, 2009, 11(2): 125-136.

[10] BENJAPHRAGAIRAT J, SAKURAI H, ITO N. Design and control of metering system and furrow openers for garlic planter [J]. International Agricultural Engineering Journal, 2010, 19(2): 39-47.

[11] BAKHTIARI M R. Determining physical and aerodynamic properties of garlic to design and develop of a pneumatic garlic clove metering system [J]. Agricultural Engineering International: CIGR Journal, 2015, 17(1).

[12] BRAVO M A, DUIMOVIC M A. Cropping conditions that affect the incidence of lateral shoots in plants of white garlic (Allium sativum L.)[J]. Cienc. Investig. Agrar, 1978, 5: 225-229.

[13] AHN Y K, CHOI G L, CHOI H S, et al. Effect of planting depth and angle of non-cloved bulb garlics on the garlic growth and yield [J]. Korean Journal of Horticultural Science & Technology, 2007, 25(2): 82-88.

[14] PAN L, DENG S J, LIU R H. Research on the identification of the roots of garlic base on pattern recognition [J]. Journal of Agricultural Mechanization Research, 2010, 32(5): 51-54.

[15] HAQUE M S, WADA T, HATTORI K. Anatomical changes during in vitro direct formation of shoot bud from root tips in garlic (Allium sativum L.) [J]. Plant production science, 1999, 2(2): 146-153.

[16] DEBAUCHE O, MAHMOUDI S, MAHMOUDI S A, et al. Edge computing and artificial intelligence for real-time poultry monitoring [J]. Procedia Computer Science, 2020, 175: 534-541.

[17] HAN Y, XIAO H R, SONG Z Y, et al. Design and experiments of 4CJ-1200 self-propelled tea plucking machine [J]. International Journal of Agricultural and Biological Engineering, 2021, 14(6): 75-84.

[18] CHEN Y T, WU C C, CHEN S F. Application of deep learning algorithm on tea shoot identification and localization [C]// 2018 ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers, 2018: 1.

[19] CHEN Y T, CHEN S F. Localizing plucking points of tea leaves using deep convolutional neural networks [J]. Computers and Electronics in Agriculture, 2020, 171: 105298.

[20] QI F, XIE Z Q, TANG Z, et al. Related study based on Otsu watershed algorithm and new squeeze-and-excitation networks for segmentation and level classification of tea buds [J]. Neural Processing Letters, 2021, 53: 2261-2275.

基于并联机器人的蒜瓣种芽朝向调整系统的设计与优化

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摘要：蒜瓣种芽朝上播种的大蒜具有出苗早，蒜苗强壮的特点，是符合中国农艺要求的播种方法。为了提高大蒜机械化播种水平，针对目前大蒜机械化播种种芽朝上率低的问题，研究设计了一种基于并联机器人的蒜瓣种芽朝向调整系统，该系统主要包括四个模块：图像采集、图像预处理、种芽特征提取和指令驱动。首先，蒜瓣运至指定位置后，并联机器人发出的光触发信号，视觉系统接收该信号并立即采集图像。其次，通过对图像进行中值滤波、二值化和形态学处理，填充孔洞，滤除背景颗粒，得到理想的二值图像，并根据蒜瓣的大小范围对二值图像的连通域面积进行筛选，得到大小合适的蒜瓣二值图像。第三，提取并计算图像的中心轮廓和轮廓的曲率，将曲率最大的部分视为蒜瓣的种芽，从而确定蒜瓣的中心位置及朝向，该朝向信息也会被量化为角度值。最后，并联机器人根据蒜瓣的位置信息、速度矢量信息和朝向信息控制机械臂进行蒜瓣抓取和定向摆放的操作，实现蒜瓣种芽朝向的调整。最后本文对调整系统的关键参数进行了试验测试，建立了调整成功率的多元回归模型，结果表明：(1)蒜瓣重量、输送速度和抓取时间对调整成功率有重要影响。(2)影响因素的主次顺序依次为抓取时间、蒜瓣重量、输送速度。(3)当蒜瓣质量为4.54 g，输送速度为0.1 m/s，并且抓取时间为2.445 s时，模型预测的调整成功率最高，达到97.41%。本研究为蒜瓣种芽调整系统的应用提供了技术指导，有助于解决利用嵌入式工控机调整蒜瓣朝向的问题，有利于促进国内大蒜机械化播种。

关键词：并联机器人；种芽朝上播种；控制系统；朝向调整；视觉系统