Design and application of visual system in the Agaricus bisporus picking robot

Hu Xiaomei¹,a, Wang Chuan¹ and Yu Tao¹,2

¹The Key Laboratory of Intelligent Manufacturing and Robotics, School of Mechatronic Engineering and Automation, Shanghai University, Shanghai, China
²School of Mechatronic Engineering and Automation, Shanghai Second Polytechnic University, Shanghai, China

a Corresponding author: sufeimasohxm@163.com

Abstract. The Agaricus bisporus picking robot has not been commercially applied in the world. Based on the self-developed A. bisporus picking robot, the visual system design is carried out, and aiming at the specificity of the picking object, a measuring method of diameter and center point position based on monocular vision is proposed. Since the unequal heights of the A. bisporus affect the accuracy of visual recognition, the three-dimensional coordinates of the centre point of the A. bisporus are measured by the horizontal movement of the camera and the ellipse-fitting algorithm is proposed to improve the accuracy of position. Moreover, the depth information is used to compensate the error of the diameter measurement of A. bisporus. Through the picking experiment at the A. bisporus planting base, the results prove that the recognition success rate of the visual system is up to 90%.

1. Introduction

Most of A. bisporus planting bases still use labor for picking and sorting in the world. The efficient of manual picking A. bisporus is less, and it is difficult to achieve picking A. bisporus 24/7. Meanwhile, everyone evaluates the quality of A. bisporus by the naked eye, which fatigues people after a long time. In addition, the evaluation criteria of people are different, so that the quality classifications of A. bisporus are not rigorous enough. It is an inevitable trend to develop A. bisporus picking robot to achieve automatic picking and classification. Machine vision technology is a key technology for the A. bisporus picking robot [1].

In recent years, with the rapid development of machine vision technology, it has been widely used in industrial manufacturing, product packaging, logistics, unmanned driving, etc. [2], but the application of machine vision technology in agriculture is full of difficulties and challenges because the growth environment of crops is full of uncontrollable factors [3,4]. A. bisporus have different postures during the growth process. Sometimes, multiple A. bisporus cluster growth and their roots connect together, which will adversely affect the recognition and position of A. bisporus.

According to the growth characteristics of A. bisporus, the A. bisporus picking robot is developed independently and the visual system design is carried out. The visual system measures the three-dimensional coordinates of the centre point of A. bisporus by horizontal movement of monocular camera, and compensates the error of the diameter measurement of A. bisporus by nonlinear model of perspective projection error.
2. Design of vision system in A. bisporus picking robot

The overall layout of the picking robot is shown in the Figure 1. There are three areas: visual area, picking area and auxiliary area. The diameter of the A. bisporus and the coordinates of its centre point can be measured in the visual area, and the collecting device can pick up A. bisporus with a diameter larger than 30 mm in the picking area by moving the X (long) and Y (wide) axes. Meanwhile, the positioning error in X and Y coordinate system of the centre point of A. bisporus should be less than or equal to 3 mm to ensure that the device can complete the picking of A. bisporus. Moreover, the diameter measurement error should be less than or equal to 1 mm.

![Figure 1. A. bisporus picking robot](image)

2.1. Vision system model of A. bisporus picking robot

According to the principle of the parallel binocular stereo vision [5], the design of the vision system model shown in Figure 2 is made. One camera moves from the position $M$ to the position $N$ along the guideway to obtain two images at different viewpoints, and the distance between the positions $M$ and $N$ is the baseline $b$ for binocular stereo vision.

![Figure 2. Visual system model of A. bisporus picking robot](image)

The centre point $P_w(x, y, z)$ of an A. bisporus on the culture shelf correspond to $P_{c1}(u_1, v_1)$ and $P_{c2}(u_2, v_2)$ in the image coordinate system of the $M$ and $N$ positions, respectively. If the direction of the guide way is the X-axis direction of the camera coordinate system, then $v_1 = v_2$, the parallax is set as $U = |u_2 - u_1|$, and the focal length is set as $f$. The coordinates of the centre point of this A. bisporus in the binocular vision system coordinate system are:

$$ z = \frac{bf}{U} \quad (1) $$

$$ x = \frac{bu_1}{U} = \frac{u_1z}{f} \quad (2) $$
\[ y = \frac{b v_1}{U} = \frac{v_1 z}{f} \]  

(3)

2.2 Hardware platform of visual system in A. bisporus picking robot

The visual hardware system mainly includes camera, lens, light source, IPC (Industrial Personal Computer) and their mechanical fixing mechanism. The CPU of IPC is Inter Core i7-3610QE. Its basic frequency is 2.3GHz, the running memory is 4.0GB, and the operating system is Windows 10. The image processing software is Halcon 13, and the images are processed in real-time in Visual Studio 2017. The camera is a 3 million-pixel industrial camera, and the camera's CMOS size is \( \frac{1}{2} '' \). The focal length of the lens is 4mm. In order to improve the uniformity and quality of illumination, the white light opening backlight is used.

In order to ensure the horizontal movement accuracy of the camera, the sliding table module whose repositioning precision achieving 0.02 mm is adopted, and its effective movement is 1100 mm. As shown in Figure 3, the visual hardware platform is built. The camera and the light source are fixed on the line-glide rail, and the slider moves linearly to perform image acquisition.

![Figure 3. The visual hardware platform](image)

The visual system is calibrated by using a \( 7 \times 7 \)-mark points calibration board whose size is 120mm \( \times \) 120mm to obtain the parameters of the visual system. In order to improve the calibration accuracy, 16 calibration pictures are used for calibration. The calibration results show that the focal length is 3.9580mm and the mean error of the reconstruction results is 0.0032mm.

2.3 Selection of baseline length

According to the formulas (1), (2) and (3), baseline is a vital parameter for visual accuracy. \( \Delta x, \Delta y \) and \( \Delta z \) represent the \( X, Y, Z \)-axis measurement error of the model respectively. Because the positioning error should be less than or equal to 3 mm to ensure that the device can complete the picking of A. bisporus successfully, the positioning error in \( X \) and \( Y \) coordinate system of the centre point of A. bisporus is set as \( \Delta s \), and \( \Delta s \leq 3 \text{mm} \).

\[
\Delta s = \sqrt{\Delta x^2 + \Delta y^2} \]

Because the size of the image sensor of the camera is 6.4mm \( \times \) 4.8mm, \( |u_1| \leq 3.2 \text{mm}, |v_1| \leq 2.4 \text{mm} \). It is seen from formula (4) that \( \Delta z \leq 2.9685 \text{mm} \) to meet \( \Delta s \leq 3 \text{mm} \). The camera movement error and parallax error can cause the \( Z \)-axis measurement error \( \Delta z \) calculated by the formula as follows.

\[
\Delta z = \left| z - \frac{(b + \Delta b)f}{U + \Delta U} \right| = \frac{z^2 \Delta U - z f \Delta b}{b f + z f \Delta U} \]

(5)

The parallax error and the baseline error are set as \( \Delta U \) and \( \Delta b \). \( |\Delta U| \leq 0.0032 \text{mm}, |\Delta b| \leq 0.02 \text{mm} \). According to the actual depth information of A. bisporus in the planting base, the \( Z \)-axis coordinate can be set as 115mm \( \leq z \leq 135 \text{mm} \). It is seen from formula (5) that the baseline length \( b \geq 4.2837 \text{mm} \) to meet \( \Delta z \leq 2.9685 \text{mm} \). The larger the baseline length, the smaller the measurement error is. Meanwhile, the larger the baseline length, the smaller the overlap area of the two pictures from \( M, N \) positions will be. Thus, the baseline length is set as 5.5mm.
2.4 Visual workflow of A. bisporus picking robot
The visual workflow of A. bisporus picking robot is as follow:

1. The visual system of A. bisporus picking robot collects images at M and N positions respectively.
2. The distortion corrections are carried out for the M and N position images.
3. The two images are transformed from RGB color space to HSV color space, and a simple threshold segmentation algorithm is used to separate the A. bisporus and soil. The segmented regions of the A. bisporus are processed by the corrosion and expansion operator.
4. XLD (eXtended Line Descriptions) contours are extracted from the Agarius bisporus regions, and the XLD contours are elliptically fitted to calculate the centre point coordinates \( (u_1, v_1), (u_2, v_2) \) and diameter of each A. bisporus equal the long axis of the fitted ellipse.
5. The template matching of each fitted ellipse is carried out, and the parallax \( U \) is calculated.
6. According to the formulas (1), (2) and (3), the spatial coordinates \( (x, y, z) \) of the centre point of each A. bisporus in the camera coordinate system are calculated.
7. The error of diameter measurement of A. bisporus is compensated according to the Z-axis coordinate of the centre point of A. bisporus.

3. Visual error correction of the A. bisporus picking robot

3.1. The contour fitting error
The contour fitting error affects the measurement accuracy of the diameter of A. bisporus and the accuracy of centre point positioning. According to the general algebraic formula of ellipse, the ellipse fitting objective function shown as formula (6) can be calculated by the least square method [6].

\[
f(A, B, C, D, E, F) = \sum_{i=1}^{N} \left( A x_i^2 + B x_i y_i + C y_i^2 + D x_i + E y_i + F \right)^2
\]

Among this function: \( i = 1, 2, \ldots, N \) and \( N \) is the number of sample points on the contour. However, the contour of A. bisporus fitted is affected easily by the edge discrete points that affect the measurement of the diameter of A. bisporus and the centre point position, as shown in Figure 4.

![Figure 4. Influence of outliers](image)

In order to make the ellipse fitting algorithm more robust, the method of joining weights can be used to reduce the influence of outliers. The Huber weight function shown as formula (7) is commonly used.

\[
\omega(\delta) = \begin{cases} 
1 & |\delta| \leq \tau \\
\frac{\tau}{|\delta|} & |\delta| > \tau 
\end{cases}
\]

The parameter \( \delta \) represents the distance from the outlier to the fitting ellipse, and the greater the distance, the smaller the weight \( \omega \) will be. \( \tau \) represents the distance threshold, and the smaller \( \tau \), the smaller the weight is given to outlier. The improved ellipse fitting objective function is shown as the following.

\[
f(A, B, C, D, E, F) = \sum_{i=1}^{N} \omega(\delta) \left( A x_i^2 + B x_i y_i + C y_i^2 + D x_i + E y_i + F \right)^2
\]
The results of experiments show that the fitting ellipse of the edge of A. bisporus is ideal when \( \tau = 2 \). As shown in Figure 5. This method can almost eliminate the contour fitting error of A. bisporus.

Figure 5. Fitting ellipse with Huber weights

### 3.2 Diameter error compensation of A. bisporus

According to the nonlinear model of perspective projection error [7], the perspective projection error \( \Delta L \) of the diameter of A. bisporus is calculated by the formula as follows.

\[
\Delta L = \frac{-L}{H_0 - f - z} \quad (9)
\]

\( L \) represents the real diameter of A. bisporus, \( H_0 \) represents the distance from the calibration plane to the lens, \( f \) represents the focal length of the lens, and \( \Delta H \) represents the distance from the centre point of the A. bisporus to the calibration plane, and \( \Delta H \) is calculated according to the Z-axis coordinate of the centre point of A. bisporus by the formula as follows.

\[
\Delta H = H_0 - f - z \quad (10)
\]

The error of diameter measurement of A. bisporus can be compensated by the formula as follows.

\[
L_c = \bar{L} + \Delta L = \bar{L} + \frac{-L}{H_0 - f - z} \quad (11)
\]

\( L_c \) represents the compensated diameter of A. bisporus. \( \bar{L} \) represents the uncompensated diameter of A. bisporus.

### 4. Experimental results and application analysis

Firstly, the experiment was made in the laboratory by simulating the actual depth of 115mm~135mm of A. bisporus, as shown in the Figure 6. In order to measure the error of the vision system, some 3D printed A. bisporus were inserted on a standard board of A0 size. From the reference point of the vision system, the A. bisporus was photographed in five positions to obtain their final coordinates. The accuracy of the vision system is measured by comparing the obtained coordinates by the vision system with the real coordinates on the chessboard.

Figure 6. Visual accuracy experiment

In addition, the experiment of picking A. bisporus was made in the edible fungus base of Shanghai Lianzhong, and the success rate of recognition, centre point positioning and picking of the A. bisporus picking robot were statistically analyzed.

### 4.1 Analysis of experimental results

In the laboratory, a number of A. bisporus were tested at different sizes (ranging from 30 mm to 50 mm in diameter), different positions, different postures (inclined 5, 10, 15, 20, 25 degrees), and different heights. 20 groups of experimental results were counted as shown in Table 1.
Table 1. The experimental results in laboratory

| Error              | Average | Standard deviation | Success rate |
|--------------------|---------|--------------------|--------------|
| Positioning error  | 1.82mm  | 2.04mm             | 95%          |
| Diameter error     | 0.2931mm| 0.8005mm           | 90%          |

4.2 Application analysis

The visual system can recognize $140\text{mm} \times 200\text{mm}$ effective area in each shot. It can collect images in five positions continuously to recognize the $140\text{mm} \times 1000\text{mm}$ area of A. bisporus. The recognition and picking experiment was made for $1400\text{mm} \times 1000\text{mm}$ area of A. bisporus. There were 497 ripe A. bisporus, and the height of ripe A. bisporus was between 40 mm and 60 mm. The diameter of ripe A. bisporus was generally between 30 mm and 50 mm. Total images processing time of the visual system was 150s, and the experimental results were shown in the Table 2.

Table 2. The experimental results in the base

| Style              | Number of success | Success rate |
|--------------------|-------------------|--------------|
| Effective recognition | 487               | 97.99%       |
| Effective position     | 465               | 93.56%       |
| Effective picking      | 457               | 91.95%       |

5. Conclusion

Aiming at the A. bisporus on the culture shelf, a measuring method of diameter and center point position based on monocular vision is proposed. The spatial coordinates of the centre point of the A. bisporus are measured with the images acquired by monocular camera that can move at two different viewpoints horizontally, and the ellipse-fitting algorithm introduced Huber weights to reduce the influence of outliers is used to improve the accuracy of visual system, and the perspective projection error of the diameter of A. bisporus is compensated according to the Z-axis coordinates. Experiments in the laboratory and the A. bisporus planting base showed that the recognition rate of the visual system of the A. bisporus picking robot was over 90%, which can meet the working requirements of the A. bisporus picking robot.

References

[1] T. Hazisawa, M. Toda, T. Sakoi. Image analysis method for grading raw shiitake Agaricus bisporus. Incheon, 46-52(2013)
[2] G. Fantoni, M. Santochi, G. Dini, K. Tracht, B. Scholz-Reiter, J. Fleischer, T.K. Lien, G. Seliger, G. Reinhart, J. Franke, H.N. Hansen, A. Verl, Grasping devices and methods in automated production processes. CIRP Annals- Manufacturing Technology, 63(2): 679-701 (2014)
[3] R. Xiang, YB. Ying, HY. Jiang. Development of real-time recognition and localization methods for fruits and vegetables in field. Transactions of the Chinese Society for Agricultural Machinery, 44(11):208-223(2013)
[4] J.R.Cai, X.J.Zhou, Y.L.Li. Recognition of mature oranges in natural scene based on machine vision. Transactions of the CSAE, 24(1):175-178. (2008)
[5] H.Yu, T.W.Xing, X. Jia. The analysis of measurement accuracy of the parallel binocular stereo vision system. Proceedings of SPIE, 32-35(2016)
[6] W.G.Wang, S.R.Wang, Z.F. Xu, et al. Optimal Ellipse Fitting Algorithm of Least Square Principle Based on Boundary. Computer Technology and Development, 23(4):67-70(2013)
[7] Z.SUN, Z.P.XU, Y.Q.WANG, et al. Control and compensation of perspective projection error analysis in machine vision measurement. Computer Engineering and Applications, 54 (2) : 266-270(2018)