Design of an Online Quality Inspection and Sorting System for Fresh Button Mushrooms (*Agaricus bisporus*) Using Machine Vision

Fengli Jiang, Xin Yang, Yunuo Wang, Lei Yang, Bingxin Sun*

***Abstract*— An online quality inspection and sorting system for fresh button mushrooms was developed based on machine vision. Mushrooms were sorted into four grades by the cap size, defects and browning. The existing grading device only considered the quality of the cap and ignored the quality of the stem. In order to get the full surface information of mushrooms, a flipping mechanism was designed to flip over the mushrooms in our system. The watershed algorithm was used to obtain the size of mushroom, and the Speeded-up Robust Features (SURF) algorithm was utilized to determine the defects. By converting the RGB image into *Lab* image, the *L* value was acquired to determine the degree of browning. Through comprehensive analysis of the cap size, defects and browning, the quality detection and classification of mushrooms were achieved. A total of 100 mushrooms were inspected and sorted to verify the performance of the prototype system. The results showed that the quality inspection of a mushroom could be finished in 0.4 s and the sorting machine could sort 72 mushrooms per minute with an average accuracy rate of 96.45 %.**

***Index Terms*— Machine vision; *Agaricus bisporus*; flipping mechanism; sorting; image processing**

I. INTRODUCTION

AGARICUS *bisporus* (*A. bisporus*), also known as button mushroom, is white in color and delicious in taste, and has high nutritional and medicinal value [1]-[2]. Furthermore, it is one of the most widely cultivated and consumed edible fungi [3]. At present, the production of *A. bisporus* has been industrialized, and the daily output of some large plants can reach hundreds of tons [4]. Facing such a huge production, manual classification becomes helpless, and must be substituted by automatic classification. Fresh mushrooms have delicate tissue and are prone to mechanical damage during harvesting and processing, leading to surface defects and browning [5]-[6]. Therefore, cap size, defects and browning are the main quality indicators for quality inspection and grading of fresh mushrooms.

Machine vision technology is used in various fields [7]-[8]. Recently, the sorting of agricultural products has been widely studied [9]-[11], and its application in the quality detection of edible fungi has also been rapidly developed [12]-[15]. For example, reference [14] used computer vision technology to identify shiitake mushrooms with varying degree of defects, and the overall recognition rate reached 96.5%. Reference [15] designed an online grading system of dried shiitake mushrooms based on size, color and damage, and classified 250 mushrooms with an accuracy rate of 97.6%. An automatic sorting system for fresh button mushrooms in terms of size was developed in [16], watershed method, canny operator and closed operation were used to grade mushrooms in this system. However, the current classification systems were mainly developed for the quality of mushroom caps. The quality of the stem side was usually ignored. Therefore, achieving the full surface information acquisition is crucial for the design of classification systems. To do this, we need to flip over the mushrooms and then analyze the both side information of mushrooms.

In this study, a quality inspection and sorting system was developed based on machine vision. First, the mushroom images of both sides were acquired. And then, three quality indicators i.e. cap size, defects and browning were analyzed by image processing algorithms such as Otsu threshold segmentation, watershed algorithm and SURF algorithm and so on. Finally, the mushrooms were classified into four levels based on three indicators.

II. MATERIALS AND METHODS

The automatic sorting system for fresh button mushrooms was designed and then implemented in hardware and software. We devised the mechanical parts, wrote the programs to control the system and process the images.

A. Hardware design

Overall structural design

The sorting system (See Fig.1) consists of a conveying mechanism, image acquisition module, flipping mechanism, control section and a sorting actuator. The machine size is about $2000\text{mm} \times 500\text{mm} \times 1390\text{mm}$. In this system, the conveying mechanism comprises a mushroom bin, two conveyor belts (the upper one and the lower one), rollers, guide rail and motors. The image acquisition module includes an embedded segment (raspberry pi) and two dark boxes. A camera (resolution 3264×2448) and a ring-shaped LED light are fixed at the top of each box. There is a flipping mechanism between two dark boxes to flip over the mushrooms. Thus, the full surface information of mushrooms can be acquired. The control section is

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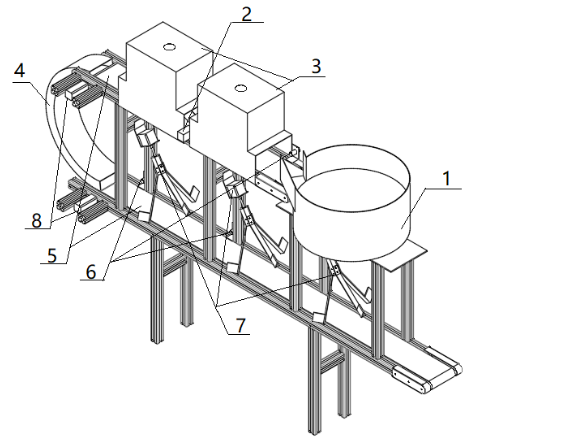
composed of PLC, relays and photoelectric sensors. The sorting actuator consists of three identical grading claws.



1. Mushroom bin. 2. Flipping mechanism. 3. Image acquisition module. 4.Guide rail. 5. Conveyor belts. 6. Photoelectric sensors. 7. Grading claws. 8. Motors.
Fig.1. The structure diagram of automatic sorting system.

Mushroom bin

The mushrooms are placed in a rotating mushroom bin and are transported to the conveyor belt under the action of centrifugal force. Once the photoelectric sensor at the exit of the bin detects the mushrooms, the conveyor will start to run.

Flipping mechanism

Mushrooms have different sizes and are nearly spherical in shape, which makes them difficult to flip. The flipping mechanism (shown in Fig.2) consists of two spring mechanisms, two iron sheets and a sensor. The one end of the two iron sheets is fixed, and the other end can open with a maximum opening of 15 cm and a minimum opening of 1 cm.

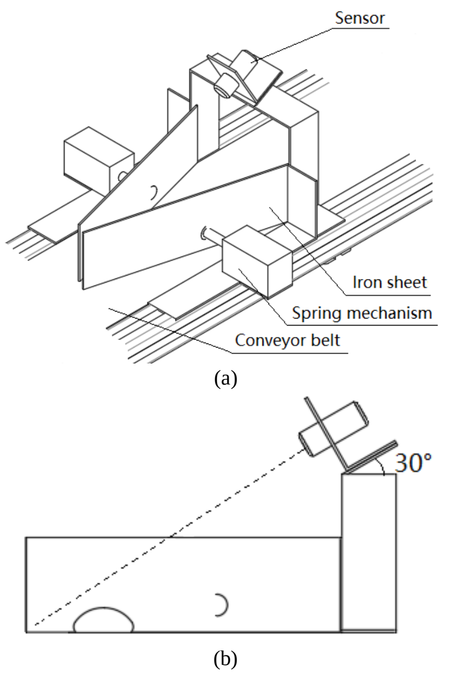


Fig. 2. Flipping mechanism. (a) Overall structure; (b) Side view

Fig. 2(b) is a side view of the flipping mechanism. The mushroom on the conveyor belt is blocked by the iron sheets and stands up under the friction between it and the conveyor belt. Subsequently, the sensor detects the signal of the mushroom, and then opens the iron sheets to flip over the mushroom. The flipped mushroom enters the next dark box.

Sorting actuator

The sorting actuator is composed of three identical grading claws (shown in Fig.3). Each claw consists of a hexagonal prism driven by a motor and three iron sheets fixed on the prism. The iron sheets are covered with flexible material to avoid damaging the mushrooms. Once the mushroom signal is detected, the prism will rotate 120° and push the mushrooms into different grading baskets through the grading claws. This rotating grading claw can realize continuous work and does not require return time compared with the traditional air pump operation.

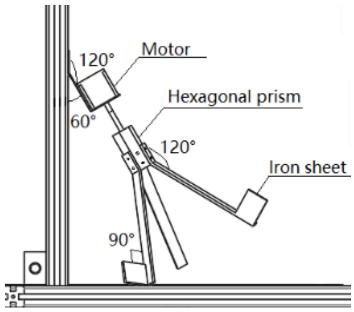


Fig. 3. Grading claw.

Operating procedure

In this system, the motors, the conveyors, flipping mechanism, cameras, grading claws and sensors are all controlled by PLC. The PLC communicates with a raspberry pi. The raspberry pi processes the image information of the mushroom size, defects, and browning. After the comprehensive judgment of the three indicators, the classification results can be obtained and are sent to the PLC.

The work-flow of automatic sorting system is shown in Fig.4.

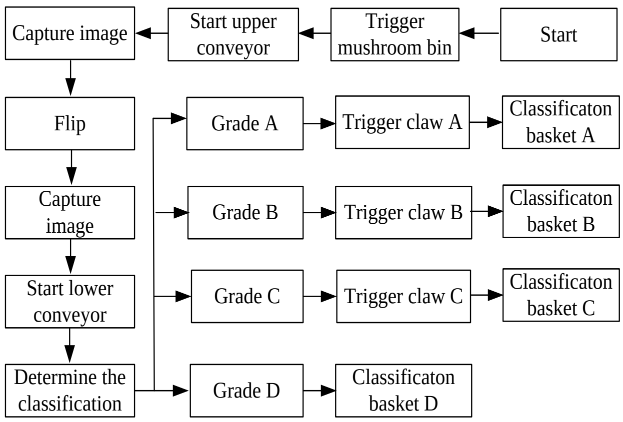


Fig. 4. System work-flow diagram.

When the mushroom is delivered to the first dark box, the camera acquires one side image of the mushroom. The mushroom is then transported to the flipping mechanism, and enters the second dark box where the camera is ready to acquire the other side image. After image acquisition, the mushroom slides down the guide rail to the lower conveyor belt and is transported to the sorting area. Then the grading claw pushes the mushroom into the corresponding classification basket according to the results of the image processing. The three grading claws correspond to the grades A, B and C along the running direction. The mushrooms of the grade D with the lowest quality will be transported directly to the sorting basket by the conveyor belt.

B. Image processing algorithms

The grading criteria for *A. bisporus* described by the industry standard are quite ambiguous. In this study, the classification of mushrooms is mainly based on three quality indicators: size, defects and browning. The indicators of size and browning are divided into four levels according to the cap size and brightness (*L* value), respectively, and the defects is divided into two levels according to whether there are defects. Based on a comprehensive analysis of three indicators, the mushrooms are divided into four grades of A, B, C, and D. Software flow diagram is shown in Fig. 5.

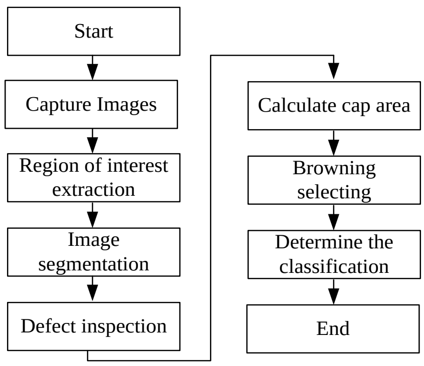
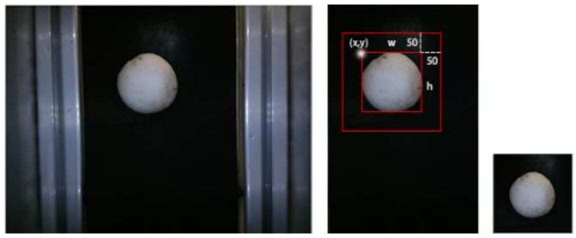


Fig.5. Software flow diagram.

Region of interest extraction

The original image captured by the camera includes the conveyor belt and borders (shown in Fig.6 (a)). In order to accurately obtain the characteristic parameters of *A. bisporus*, the region of interest is extracted from the original image for subsequent image processing. First, the aluminum frame is removed from the image by the Minimum enclosing rectangle method (see Fig.6 (b)). Then, the three values of the smallest circumscribed rectangle for the mushroom are calculated, which are the upper left point (*x*, *y*), the width *w* and height *h* of the rectangle, respectively. Finally, the above rectangle is extended 50 pixels outward to obtain a new rectangle with the width (*w* + 100) and the height (*h* + 100) (as shown in Fig. 6 (c)).



(a) (b) (c)

Fig.6. Extraction for region of interest. (a) Original image; (b) Border removing; (c) Region of interest

Watershed algorithm

The watershed method is used to extract the contours of the image on both sides of *A. bisporus* (as shown in Fig.7).

Taking the cap side image as an example, the specific process is as follows:

Step 1: Convert the original image Fig.7 (a1) into a grayscale image Fig.7 (b1) first and then into a binary image Fig.7 (c1) using the Otsu threshold segmentation algorithm.

Step 2: Perform the closed operation of morphological transformation to remove noise data (the small black holes and cracks). The improved image Fig.7 (d1) is obtained after 17 iterations of the closed operations.

Step 3: Perform the dilation operation for 10 times to obtain background image Fig.7 (e1).

Step 4: Get the normalized image Fig.7 (f1) and the foreground image Fig.7 (g1) by distance transformation.

Step 5: Subtract the background from the foreground to determine the uncertain area where the foreground and background overlap and mark the area.

Step 6: The boundary of the original image (Fig. 7 (h1)) is finally obtained according to the watershed transformation of the marked uncertain region.

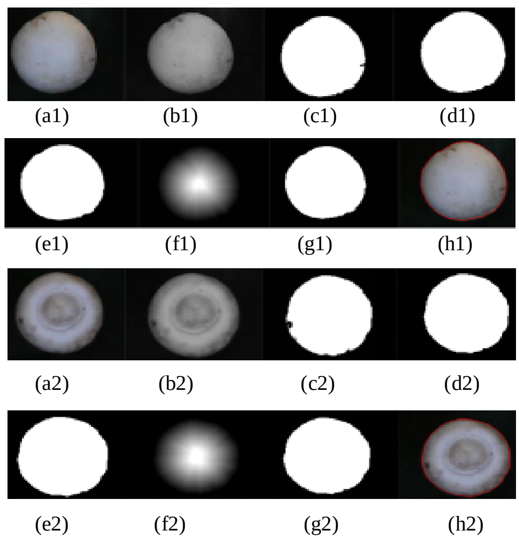


Fig.7. Watershed transformation of *A. bisporus*.(a1-a2)Original image; (b1-b2) Grayscale image; (c1-c2)Binary image; (d1-d2) Morphological transformation; (e1-e2) Dilation image; (f1-f2)Distance transformation; (g1-g2)Foreground image; (h1-h2)Image contour

C. Mushroom features

Size

Generally, the diameter of mushroom as the characteristic parameter of size can be converted by area. According to the boundary image obtained in Section *Watershed algorithm*, calculate the number of pixels of the image (*m*). Thus, the area (*S*) of the mushroom is calculated as:

$$S = m * 25.4 / 96 \quad (1)$$

In (1), the unit of S is mm^2 and the camera in this study has a resolution of 96.

Calculate the area of both sides of the mushroom, and the larger one is used as the final area.

In this study, the size of mushrooms was decided into 4 levels of "large, medium, small, and very small". Mushroom size sorting rules are shown in Table 1.

TABLE I
THE RULES FOR CAP SIZE

Level	Diameter (mm)	Area (mm^2)	Pixel (numbers)
1	diameter >45	area>1589.63	pixel>177
2	25≤diameter≤45	490.63≤area≤1589.63	55≤pixel≤177
3	10≤diameter < 25	78.5≤area< 490.63	9≤pixel<55
4	diameter<10	area<78.5	pixel<9

Defect

The defects of mushrooms are usually caused by mechanical stress during harvesting and handling [17]. Obvious bruises and defects can be easily identified based on machine vision. However, it is difficult to check for minor damages and defects.

The Speeded-up Robust Features algorithm (SURF) is a modified algorithm based on the Scale-invariant Feature Transform algorithm (SIFT) [18]. It was proposed by Bay at the European Conference on Computer Vision in 2008 [19]. As a feature extraction algorithm, SURF brings an obvious advantage in computational speed, and performs excellently robustness. The algorithm does not depend on pixel values and is less affected by shooting angle. The SURF algorithm mainly includes two parts: extraction and description of feature points.

Feature point extraction

To extract feature points, Hessian matrix is needed to construct first. The Hessian matrix $H(X, \sigma)$ of any point $X = (x, y)$ in the image I is as follows:

$$H(X,\sigma)=\begin{bmatrix} L_{xx}(X,\sigma) & L_{xy}(X,\sigma) \\ L_{xy}(X,\sigma) & L_{yy}(X,\sigma) \end{bmatrix} \quad (2)$$

where $L_{xx}(X, \sigma)$, $L_{xy}(X, \sigma)$ and $L_{yy}(X, \sigma)$ are the second-order partial derivatives of point (x, y) of the image I after Gaussian filtering, respectively.

In order to find the feature points of the image, the original image needs to be converted to an integral image. And then, the convolution of the integral image and the box filter is approximated as D_{xx}, D_{xy}, D_{yy}. Therefore, the approximate Hessian determinant is calculated as:

$$\det(Hessian) = D_{xx}D_{yy} - (\lambda D_{xy})^2 \quad (3)$$

where λ is a weight coefficient, which is used to balance the error for the approximation caused by the box filter. In this study, λ=0.9.

After all the pixels processed by the Hessian matrix, non-maximum comparison between them and the points in scale space is used to find the interest points of the image. Then, a linear interpolation operation is performed in the scale space and the image space to obtain the final stable feature points.

Description of feature points

First convert the original image into a grayscale image, and then draw a circle with the feature points extracted as the center. During the experiment, a large number of tests were performed to determine the threshold for mushroom defects. The threshold for mushroom cap and stem were 22 pixels and 50 pixels, respectively. It can be seen that the threshold value of the stem side is greater than that of the cap side. If the circle size exceeds this threshold, it is considered to be defective. The results of the treatment for two sides of *A. bisporus* are shown in Fig.8.

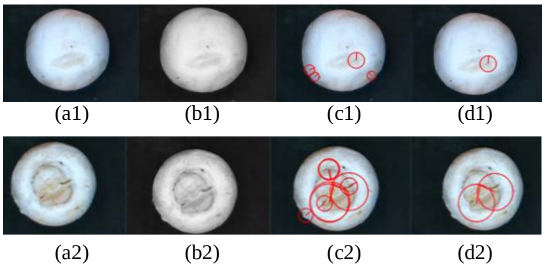


Fig.8. Defect determination. (a1)-(a2) Original image; (b1)-(b2) Grayscale image; (c1)-(c2) Feature point description; (d1)-(d2) Feature point selection

Browning

The color of *A. bisporus* is one of the most important quality indicators. High-quality mushroom is bright white, and any color deviation from white is unacceptable. Studies have shown that the L value in *Lab* images characterizes the brightness of mushrooms, and thus reflects the degree of browning. The value of L varies from 0 to 100. The larger the L value, the whiter the mushroom. Mushrooms with L value greater than 86 are classified as good, L value between 80 and 85 are fair and L value between 70 and 79 are poor, mushrooms with L value below 69 have no commercial value [20]. According to the above four ranges, mushrooms are classified into four levels of 1, 2, 3 and 4 in this study. $L \geqslant 86$ is level 1, $80 \leqslant L < 85$ is level 2, $70 \leqslant L < 79$ is level 3, and $L \leq 69$ is level 4. In this study, traverse each pixel of the cap, and get the L value. The light in the dark box is not bright enough, so the L value of the mushroom cap image actually obtained cannot reach the real value. We can obtain the lower limit value of each actual level by converting the above-mentioned four L value ranges in equal proportions. It is defined as follows:

$$\frac{L_{Ri\max} - L_{Ri}}{L_{Ri\max}} = \frac{L_{Si\max} - L_{Si\min}}{L_{Si\max}} \quad (4)$$

where L_{Ri} and $L_{Ri\max}$ are the lower limit and maximum values of the corresponding range for level i (i = 1, 2, 3, 4) in the cap image obtained by the camera, respectively; $L_{Si\max}$ and $L_{Si\min}$ are the maximum and minimum values of L corresponding to level i, respectively.

The interval range corresponding to the four levels can be obtained by (4). Count the number of pixels of L value for the first level in this interval, and then calculate the ratio of the number obtained to the total number of pixels of the cap as R. The rules are determined as:

If $R \geqslant 0.65$, the mushroom is judged as level 1. If $0.58 \leqslant R < 0.65$, the mushroom is level 2. If $0.53 \leqslant R < 0.58$, the mushroom is level 3. If R<0.53, the mushroom is level 4. The browning process is shown in Fig.9. The value of R is 0.549, so the mushroom is defined as level 3.

(a) (b) (c) (d)

Fig.9. Browning selection. (a) Original image; (b) Lab image; (c) Labeled area; (d) Defection area

D. Mushroom grade determination

The system judges the grades according to the worst principle. The overall classification is shown in Table 2.

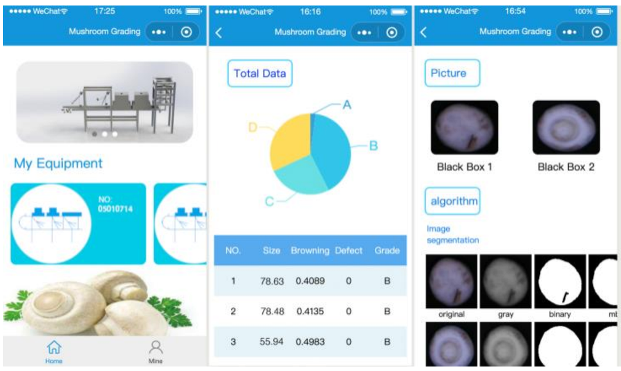
TABLE II
MUSHROOM GRADE DETERMINATION

Defect（Yes/No）	Size	Browning	Grade
No	1	1	A
No	1/2	2	B
No	2	1/2	B
No	1/2/3	3	C
No	3	1/2/3	C
Yes	X	X	D
X	4/X	X/4	D

Note: X indicate all possible values and "/"means "or".

Data visualization

The grading results of mushrooms can be displayed in real time through the mobile terminal (see Fig.10).



(a) (b) (c)

Fig.10. Mobile phone interface. (a) Homepage interface; (b) Batch mushroom data interface; (c) Single mushroom data interface

The terminal mainly includes the homepage interface; batch mushroom data interface, and single mushroom data interface. The user can query the mushroom data in different interfaces conveniently.

III. TEST RESULTS AND DISCUSSION

In order to verify the performance of the system, the experimental prototype was tested. A total of 100 fresh mushrooms were selected randomly, and the results of manual classification were used as control. The comparison results of machine classification and manual classification are given in Table 3.

TABLE III
COMPARISONS BETWEEN AUTOMATIC CLASSIFICATION AND MANUAL CLASSIFICATION

Grade	Grade-A	Grade-B	Grade-C	Grade-D
Machine (Manual)	38(37)	40(39)	20(22)	2(2)
Accuracy rate (%)	97.4%	97.5%	90.9%	100%
Average accuracy rate (%)	96.45%			

It can be seen in Table 3 that the average accuracy rate of the machine classification system is 96.45%. Validation tests show that the automatic classification system is reliable and feasible for the online classification of *A. bisporus*. It is worth noting that the detection error is mainly due to the defects and browning on the edges of mushrooms that are difficult to capture by the camera. In this test, when the conveyor belt speed of sorting machine is 0.32 m/s, the average processing time for a single mushroom is 0.4s. The average grading speed of the sorting machine can reach 72 mushrooms per minute.

IV. CONCLUSIONS

In this study, an automatic fresh *A. bisporus* sorting system was designed. One important development was the hardware design including flipping mechanism and the sorting actuator. Another development was the image processing algorithms to analyze the quality parameters such as the size, defects and browning of *A. bisporus*. And the performance of the system was verified through the experiments. The results showed that the classification accuracy of the system could reach 96.45%, indicating that the automatic classification system was feasible for the online classification of *A. bisporus*.

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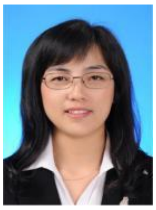

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