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Automated strawberry grading system based on image processing

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ABSTRACT

Using machine-vision technology to grade strawberries can increase the commercial value of the strawberry. The automated strawberry grading system has been set up based on three characteristics: shape, size and colour. The system can efficiently obtain the shape characteristic by drawing the lines and then class with *K*-means clustering method for the strawberry image. The colour of the strawberry adopts the Dominant Colour method into the a^* channel, and the size is described by the largest fruit diameter. The strawberry automated grading system can use one, two or three characteristics to grade the strawberry into three or four grades. In order to solve the multicharacteristic problems, the multi-attribute Decision Making Theory was adopted in this system. The system applied a conveyer belt, a camera, an image box, two photoelectrical sensors, a leading screw driven by a motor, a gripper, two limit switches and so on. The system was controlled by the single-chip-microcomputer (SCM) and a computer. The results show that the strawberry size detection error is not more than 5%, the colour grading accuracy is 88.8%, and the shape classification accuracy is above 90%. The average time to grade one strawberry is below 3 s.

1. Introduction

Automated strawberry gradation plays an important role to increase the value of produces. In general, the gradation indices are shape, size, colour, maturity, defection, etc.

With the progress in computer image vision technology, the gradation technique based on computer vision has developed. The computer vision gradation technology is real-time, objective, non-destructive, and can detect multi-index simultaneously, such as size, defection, colour, shape and the maturity.

The tomato grading system (Sarkar and Wolfe, 1985) separated oriental tomato into different grades with the information on the values of size, colour, shape and surface defection that were acquired by using image analysis and mode identify technology. According to the surface defection by using the black and white image processing, the detection of apple defection (Rehkugler and Throop, 1986) was conducted. The apple grading system (Davenel and Guizard, 1988) was completed according to the size and surface defection. The machine-vision system (Miller and Delwiche, 1989) was carried to check the fresh peach and confirm the peach maturity by comparing the peach colour to the standard hue of different maturity. The image analysis system (Nimesh et al., 1993) was developed to evaluate the colour of the stone fruit. The real-time maturity grading of fresh peach was developed to measure the 13 ground colour references used by the California Tree Fruit Agreement (CTFA). The RGB model (Choi et al., 1995) was transformed into the HIS model, the cumulating *H* distributing map of fresh tomato was divided into six maturity grades, and tomato maturity index was constructed. The potato system (Tao et al., 1995) presented a Fourier-based separation technology for shape gradation. The automated inspection station for machine-vision grading of potato (Heinemann et al., 1996) was completed. The machine-vision apple defect sorting system (Tao and Spherical, 1996; Tao and Wen, 1999) was developed by applying an adaptive spherical transform. The apple grading system of Yang (1993a, 1994, 1996) used the structural light image and general image to get sufficient information, and extracted information of characteristics that were used as input value for a Back-Propagation neural network to grade the apples. The pistachio nuts grading system (Ghazanfari, 1996) was designed by using a neural network and machine-vision system. The apple image data collecting system (Kazuhiro, 1997) was developed to sort the apple into five grades by using two neural network models. The stable model invariant to change in lighting conditions with 12 maturity classes (Edan et al., 1997) was provided based on the weighted colour parameter. The automatic rating of fruit quality (Gerhard et al., 2001) was conducted. The tomato classification (Laykin et al., 2002) by using image processing algorithms was conducted. The strawberry grading system (Masatera, 1997) was graded according to the shape and size by using image processing. The strawberry orientation and shape determination (Bato et al., 1999) was implemented by using image processing.

At present, the Chinese scholars have begun to research the fruit gradation through image processing. The apple automated

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grading system use the neural network (Xu, 1997). In order to recognize the stem, the algorithms using morphological image processing and concave–convex characteristic of edge were presented, then the size and shape were detected. The two ways were used to detect shape. Cao et al. (1997) designed a strawberry grading system driven by vacuums pump, the strawberry was pushed into different gradation by vacuum vat. The sorting index is the shape. The eight lines were drawn in shape and analyzed by the neural network system. Research on analysis of hue distribution features by artificial neural network in apple gradation has been completed by He (1998). A cucumber gradation judgment system based on image processing and neural network technology was developed for long shape fruit (Wang et al., 1999). The system can sort different fruit type after training with sample patterns of different objects. An automated apple grading system by colour was built by Li et al. (2000). A method of using HIS colour system and neural network technology for apple colour inspection was developed. The fruit neural network grading system of Feng (2002) provides two ways to inspect the image edge quickly, using the distribution of the hue in fruit surface to grade on-line.

In a word, there are several fruit gradation systems to be built. But most of them adopt one index, such as the size or the detection or the shape. For the strawberry, the surface colour could indicate the interior quality, so the surface colour is the important index to sort the strawberry.

At meanwhile, the strawberry has special shapes, such as long-taper, square, taper, rotundity and so on. Cao et al. (1997) adopted eight inputs and the neural network to sort the strawberry shape, it needed long times to train the neural network model. So in order to describe the shape perfectively and quickly, it is needed to develop another algorithm.

The objectives of this study were to develop an automated strawberry grading system using image processing by developing a new algorithm to calculate the strawberry shape, and to grade the strawberry adopting one or two or three indices among shape, colour and size.

2. Materials and methods

2.1. Design of the automated strawberry grading system

The automated strawberry grading system (Fig. 1) mainly consists of a mechanical part, an image processing part, a detection part and a control part. The mechanical part mainly consists of a conveyer belt, a platform, a leading screw, a gripper and two motors to implement the strawberry transport and gradation. The image processing part consists of camera (WV-CP470, Panasonic), image collecting card (DH-CG300, Daheng company), a closed image box and a computer (PCM9575) to implement image pre-processing, segmentation, extracting grading characteristic and to grade the strawberry by these characteristics. The detection part consists of two photoelectrical sensors and two limit switches. The photoelectrical sensors are used to detect the strawberry position; the limit switch is used to protect the slider on the leading screw during the detection. The control part adopts the single-chip-microcomputer (SCM) to receive the signals from the photoelectrical sensor, the limit switch and the computer, finally to control the motors.

Compared to existing grading systems, this automated strawberry grading system adds a closed image box so as to catch the images under the same light intensity. There are two photoelectrical sensors to control the conveyer belt. The leading screw driven by a motor could run in forward and reversal mode, and it connects to the gripper with a screw. The running leading screw could bring the gripper to move between left and right, so as to pick up the strawberry into the correct grade.

The working process of the automated strawberry grading system is described as the following:

(1) Strawberry is put on the conveyer belt by manual, advanced with the conveyer belt at a constant speed.
(2) When the first photoelectrical sensor detects the strawberry to be passing through, it sends the signal to the control part and begins to capture the strawberry images, extract the grad-

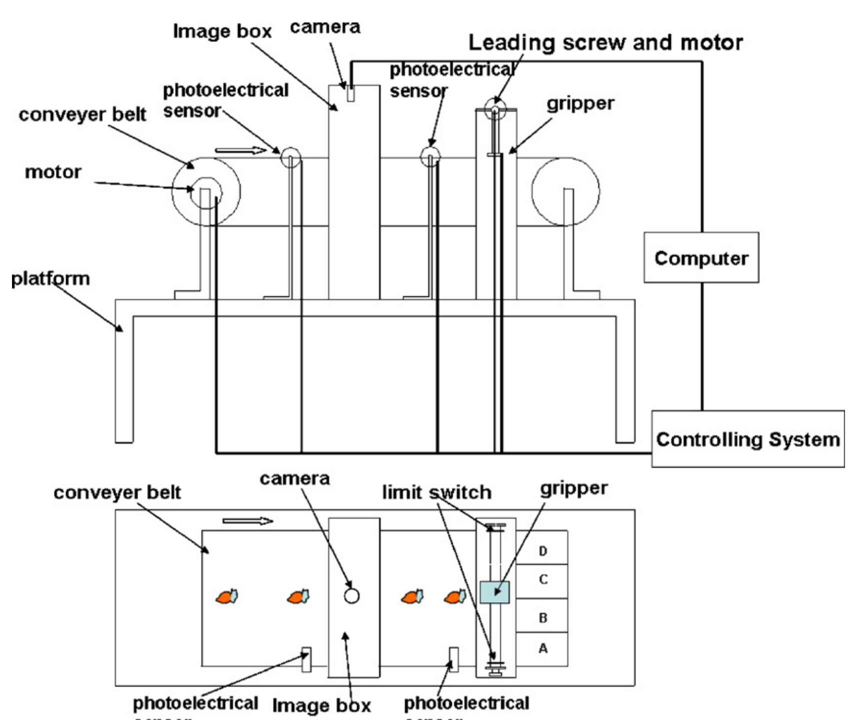

Fig. 1. The structure of the strawberry automated grading system.

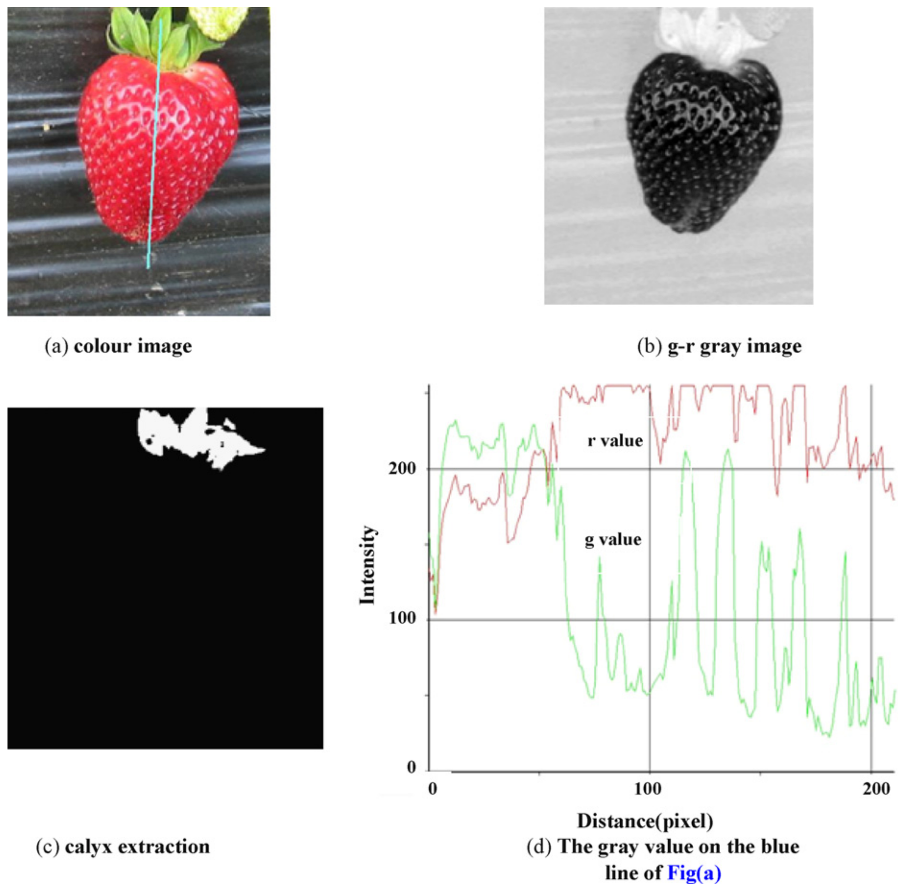

Fig. 2. The determination of the strawberry: (a) colour image, (b) g–r gray image, (c) calyx extraction, and (d) characteristic extraction by sharing line method.

ing features and determine which gradation the strawberry belongs to.

(3) As the strawberry's movement continues, when the second photoelectrical sensor detects the strawberry to pass through, the control part controls the mechanical parts to implement corresponding grade according to the result of the image processing.

(4) Repeat the step (1), until all strawberries were detected.

2.2. *Strawberry feature extraction and gradation algorithm*

(1) The strawberry position determination

The strawberries are placed on the conveyer belt at random, so the strawberry's positions are uncertain in the images captured by computer. Because there are some calyxes at the stem, the fruit position can be determined after these calyxes are found.

In Fig. 2(d), the g–r value is different among the strawberry calyx, fruit and the background. The g–r gray image converted from the colour image is shown in Fig. 2(b), it shows that the g–r value of the calyx is greater than that of the fruit and the background, so the image can be segmented by selecting a threshold. And the extracted strawberry calyx is shown in Fig. 2(c).

(2) Strawberry gradation by the single feature

The fruit gradation generally uses size, shape and colour. The automated strawberry grading system mainly extracts the three features, and implements corresponding gradation.

(1) Strawberry shape feature

The strawberry shape is too complicated to measure with a single geometry size. This paper found that the strawberry shape feature parameters can be obtained by extracting line sequences from the strawberry contour and normalizing the length of these line sequences to eliminate the influence of the strawberry size, and these parameters could express the strawberry shape well. In order to make the shape gradation adapt various kinds of strawberry, and have a faster processing speed to meet the real-time requirement, the automated strawberry grading system implemented K-means clustering method to complete the shape gradation.

K-means clustering method, put forward by Marques et al. (2002), is the optimal algorithm in clustering analysis. According to the advance class centers, the K-means clustering method could put some similar classes into one center. It is described as follows: classify n objectives into K classes with the parameter K, having a higher similarity within one class and a lower similarity among classes. This method has certain intelligence, so it can select automatically the center of a class and the measurement threshold of the similarity according to the sample's variety. Therefore, it can be applicable to various strawberry gradations.

The steps to extract the strawberry shape features are described as the following:

(a) Select the R–G channel of the strawberry image (Fig. 3(a)); select a segmentation threshold based on Outs algorithm. This method can avoid a great deal mathematic calculation caused by the colour space transform, and achieve better segmentation result (Fig. 3(b)). The segmented binary image is traced for the contour and then the strawberry's contour curve (Fig. 3(c)) is obtained.

(b) Make the fruit contour be added with the calyx contour to obtain the joining curve between the calyx and

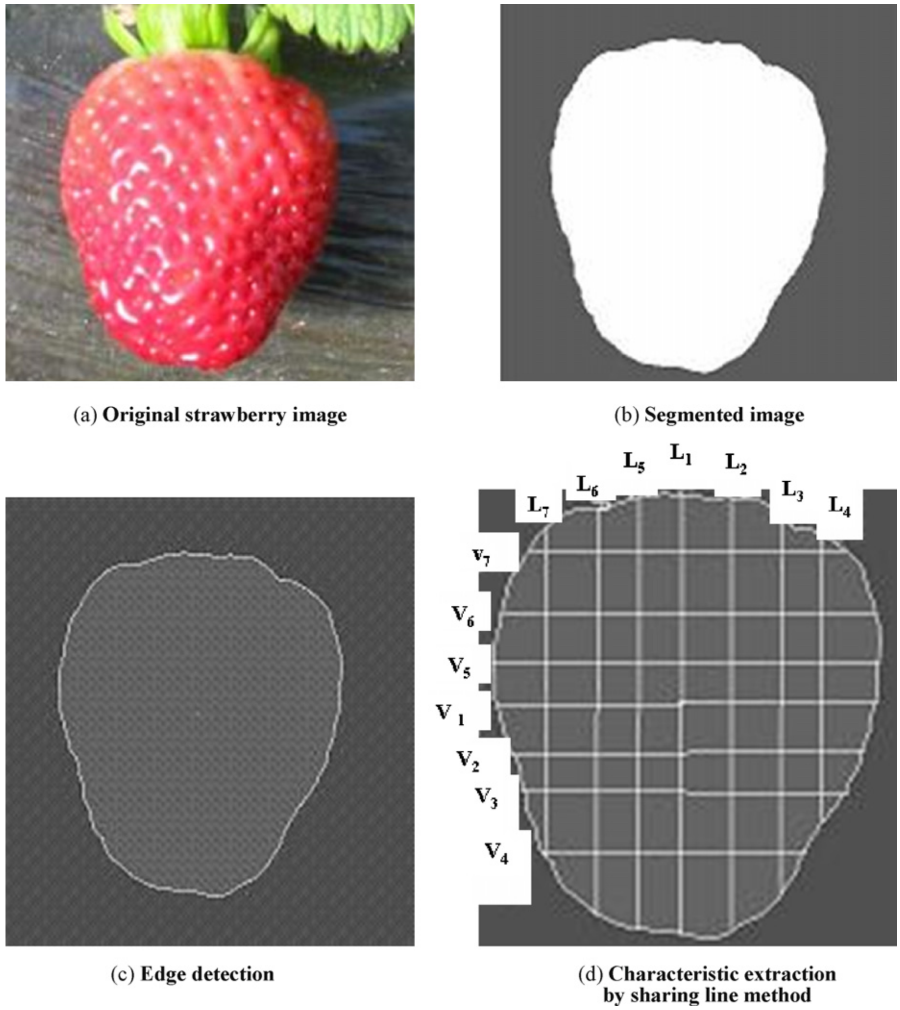

Fig. 3. The strawberry shape characteristic extraction (a) original strawberry, (b) segmented image, (c) edge detection, and (d) characteristic extraction by sharing line method.

the fruit. The joining curve center connected with the fruit gravity center to form a line l_1, i.e., the major axis direction of the strawberry.

(c) The sharing ling method is adopted to compare the shape. The strawberry is divided evenly using seven lines in horizontal direction (l_1, l_2, l_3, ..., l_7) and the direction vertical ($v_1, v_2, v_3, \ldots, v_7$), respectively, and 14 lines are obtained (Fig. 3(d)). l_1 and v_1 are passing the strawberry the gravity center, respectively.

(d) The 14 lines are obtained. Then let

$$x_{i1} = \frac{l_2}{l_1}, \quad x_{i2} = \frac{l_3}{l_1}, \ldots, x_{i6} = \frac{l_7}{l_1}$$
$$x_{i7} = \frac{v_2}{v_1}, \quad x_{i8} = \frac{v_3}{v_1}, \ldots, x_{i12} = \frac{v_7}{v_1} \tag{1}$$

The $x_{i1}, x_{i2}, \ldots, x_{i12}$ are standardizing the shape feature parameters.

(e) The line length of each strawberry is calculated. The bigger the differences in the line lengths are, the more different they are in terms of shape.

The strawberry shape gradation flow is described in Fig. 4.

According to the shape feature, this paper divided the shape into four degrees (Fig. 5): long-taper, square, taper and rotundity.

(2) Strawberry size feature

The maximum horizontal diameter is detected in the direction vertical to l_1, and the number of the pixels (N_p) on the maximum horizontal diameter is found. Under the same condition, the rate between the pixel and the actual length is fixed in the image, the rate is called A:

$$A = \frac{\text{the pixels}}{\text{the actual lengthen}} (\text{pixel/mm}) \tag{2}$$

Through a lot of trials and calculations, A is gotten: $A = 5.8$ (pixel/mm)

The actual maximum horizontal diameter D of the strawberry can be obtained by Eq. (3):

$$D = \frac{N_p}{A} = \frac{N_p}{5.8} \tag{3}$$

The strawberry size gradation is implemented by a threshold which is set according to the strawberry maximum horizontal diameter. According to the D value, the size feature is divided into four degrees:

$$\begin{aligned} &D \geq 50\,\text{mm}, \ \text{the greatest fruit} \\ &45 \geq D \prec 50\,\text{mm}, \ \text{the bigger fruit} \\ &35\,\text{mm} \leq D \prec 45\,\text{mm}, \ \text{the middle fruit} \\ &D \prec 35\,\text{mm}, \ \text{the smaller fruit} \end{aligned}$$

(3) Strawberry colour feature

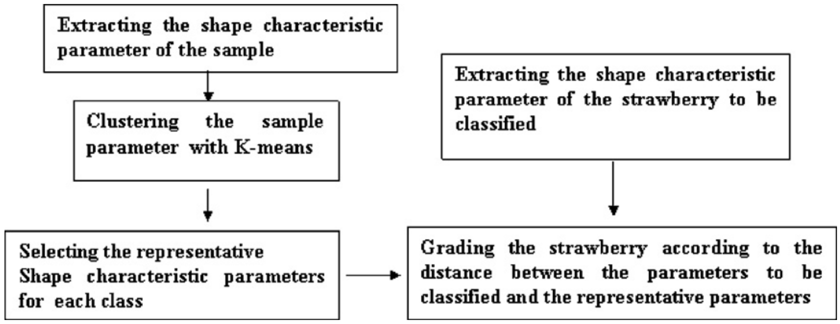

Fig. 4. The strawberry shape gradation flow chart.

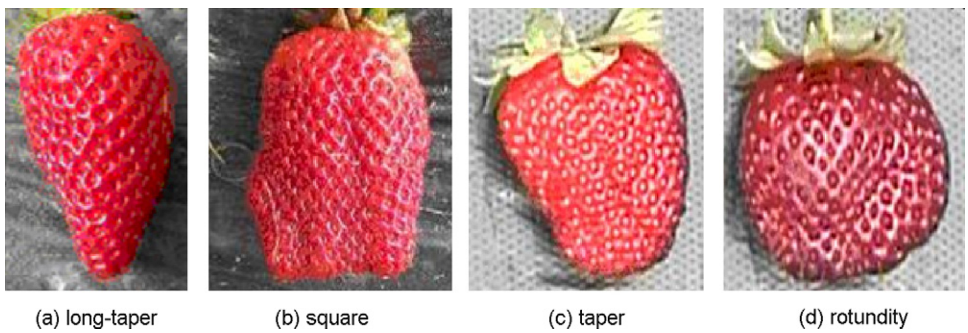

Fig. 5. Strawberry four degrees by shape: (a) long-taper,(b) square, (c) taper, and (d) rotundity.

The automated strawberry grading system used a^* channel in $L^*a^*b^*$ colour model as the basis to judge the strawberry colour.

Commonly, the human sight is more interested in the main colour in a picture, i.e., the main colour takes a dominant place in vision and appears the most times in a picture. So the strawberry colour feature is extracted by the Dominant Colour method (Fig. 6) on a^* channel. The selecting processes are described as the following:

(a) Calculate the histogram of the strawberry image on a^* channel.
(b) Set a window with the width of L to calculate the gray value of the window from the most left of the histogram.
(c) Move the window one pixel toward the right; calculate the gray value of the window.
(d) Execute step (c) repeatedly until the window is moved to the most right.

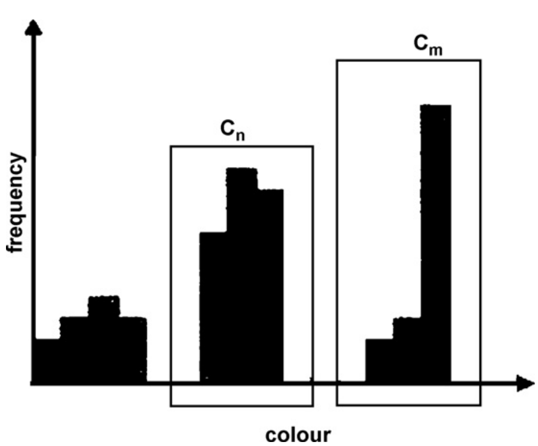

Fig. 6. The Dominant Colour method.

(e) Obtain a window with the largest frequency, i.e., the major colour window.
(f) Calculate the average colour value of the Dominant Colour window using Eq. (4):

$$\overline{AS(L)} = \frac{\sum_{L} f(C_i)}{L} \tag{4}$$

where $\overline{AS(L)}$ is the average colour value, L is the width of the histogram. $\sum_{L} f(C_i)$ is the summation of the hue value C_i of all histogram with L width.

The strawberry colour gradation is implemented with a threshold set according to the major colour value on a^* channel. According to a^* value, the colour feature is divided into three degrees:

$$\begin{cases} a* \geq 160, & \text{black-red} \\ 150 \leq a* \prec 160, & \text{bright-red} \\ a* \prec 150, & \text{light-red} \end{cases}$$

(3) Multi-features gradation

The automated strawberry grading system is designed to grade by one index or by two or three indices simultaneously.

Normally, the index conflicts with one another during multi-indices grading. For example, some strawberries have large sizes but are not mature, or, their shapes are odd so as to have an influence when they are placed together. To solve these problems, the multi-attribute Decision Making Theory is adopted in the automated strawberry grading system. It can assign different weight to different attributes of the object according to different standards to achieve the simplification of the multi-attribute problems (Eq. (5)), the ith strawberry grade can be determined with the magnitude of

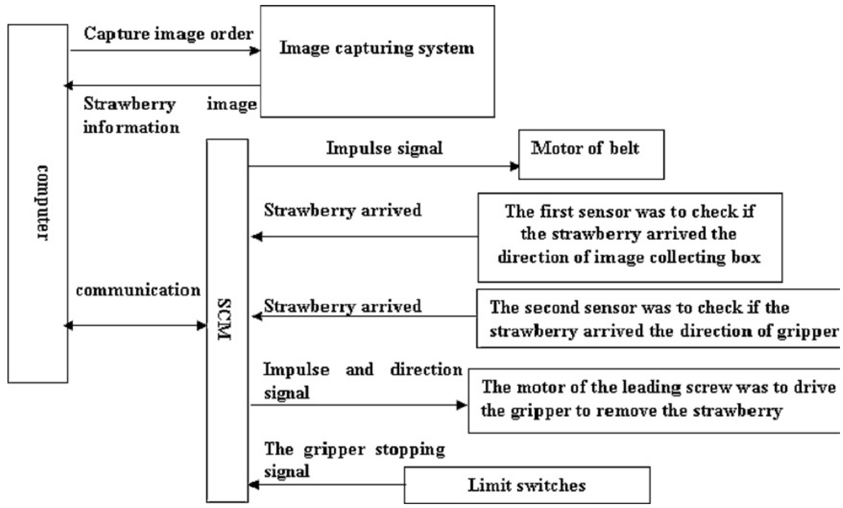

Fig. 7. The controlling system.

the index C_i ($i = 1,\ldots,m$):

$$C_i = \sum_{j=1}^{n} \omega_j z_{ij} \tag{5}$$

where ω_j is the weight of the attribution j, z_{ij} is the value of the attribution j of strawberry i. n is the number of indices to be sorted. m is the number of gradation.

In this gradation system, $j = 1, 2, 3$, expresses the size, the colour and the shape, respectively. $i = 1, 2, 3$, expresses the three gradations, i.e., the first gradation is the best, the third gradation is the worst. $\omega_1 = 3, \omega_2 = 2, \omega_3 = 1$. So the gradation is carried by the follow way:

$$\begin{cases} C \geq 54, & \text{the first strawberry} \\ 21 \leq C \prec 54, & \text{the middle strawberry} \\ C \prec 21, & \text{the third strawberry} \end{cases}$$

The automated strawberry grading system designed the human–computer interaction interface to set a threshold about the shape, size and colour in order to adapt various kinds of strawberry.

2.3. Control of the automated strawberry grading system

The control part (Fig. 7) had a computer and the SCM. The computer controlled the image capturing system and communicated with the SCM. The SCM controlled the belt motor, the leading screw motor, two sensors and two switches. The SCM chose AT89S51 to be a center unit and use VC language to compile the program.

3. Results and discussion

A series of tests have been made to validate the property of the automated strawberry grading system. Through the tests, the accuracy and real-time of the gradation algorithm compiled in the present study are validated, and the precision and the success rate of the mechanical parts are tested and analyzed. The “Tongziyihao” strawberries used in the test were picked up in Changping, Beijing.

3.1. Strawberry size gradation test

According to Eq. (3), (50) strawberries were tested; the error between the actual size and the measured size is within 5% (Table 1), which proves that Eq. (3) is viable.

3.2. Strawberry colour gradation test

The strawberry colour feature is extracted by the Dominant Colour method to implement the strawberry colour gradation. 50 strawberries were used in the test; they are divided into light-red, bright-red and black-red manually. The results of the system gradation and the manual gradation are compared; the results are following in Table 2.

In Table 2, compared with the manual gradation results, the precise rate of this system for three maturities averages 88.8%. However, It should be noted that the human sorting is also subject to error, so that 100% agreement cannot be expected. This strawberry automated grading system adopted the Dominant Colour method, it could have higher sorting precise rate.

3.3. Strawberry shape gradation test

144 strawberries were used as the sample to cluster, 80 additional strawberries were used to analyze and distinguish to validate the gradation effect of the automated strawberry grading system.

The shape features of 144 strawberries were clustered with K-means clustering algorithm and the clustering result is shown in Table 3. 13 groups feature parameters closest to the gravity center are selected to create a discriminating function. 80 additional strawberries were used to discriminate and classify. The results (Table 4) show that: there were seven strawberries not consistent with the manual gradation, among them, five strawberries were extremely abnormal shapes, and two strawberries were inclined.

Table 1
The results of some strawberry sizes.

No.	Actual diameter (mm)	Detecting results (pixel)	Calculating diameter (mm)	Error (%)
1	35.12	200	34.48	1.8
2	34.70	198	34.14	1.6
3	29.62	169	29.14	1.6
4	33.34	185	31.90	4.3
5	47.54	263	45.34	4.4
6	39.36	220	37.93	3.6
7	53.22	299	51.55	3.1
8	41.86	231	39.83	4.8
9	43.28	243	41.90	3.2
10	54.98	310	53.45	2.8

Table 2
The result of the strawberry colour feature detection.

Colour	Manual gradation (number)	System gradation (number)	Error number (number)	Exaction rate (%)	Average extraction rate (%)
Light-red	16	14	2	87.5	
Bright-red	17	20	3	85	88.8
Black-red	17	16	1	94	

Table 3
The results of strawberry *K*-means clustering.

Item	Shape			
	Long-taper	Square	Taper	Rotundity
No. of class	16	31	62	25
Using time (s)		1.67		

Table 4
The results of strawberry classification.

Item	Shape			
	Long-taper	Square	Taper	Rotundity
No. of class	13	19	36	12
No. of inconsistent	1	2	3	1
Rate (%)	7.6	10.5	8.3	8.3
Using time (s)		2.49		

Table 5
The results of the automated strawberry grading system.

No. of group	No. of the successful strawberry	Using time (s)	Successful rate (%)
1	9	25.52	90
2	8	10.78	80
3	10	24.20	100
4	10	22.31	100
5	10	21.26	100

3.4. *The whole test of automated strawberry grading system*

The whole automated strawberry grading system was conducted. 50 strawberries were divided into five groups to test. The results (Table 5) showed that all the parts are fitted together well and enable to achieve the strawberry gradation action. In the first group, some strawberry samples were too small. In the second group, the gripper could not catch the strawberry, because the belt motor was too fast, the strawberry could not stop under the gripper. After having adjusted, the system could run smoothly. In the last three groups, the system could sort successfully. The average time used to grade one strawberry is below 3 s.

4. Conclusion

In order to increase the strawberry values and found the applied, quickly and nicety algorithm, the automated strawberry grading system has been set up by using machine-vision technology. Specifically:

(1) The automated strawberry grading system was completed and divided into a mechanical part, an image processing part and a control part. The mechanical part performs the strawberry's transport and put the strawberry into the right gradation. The image processing part carries out the strawberry image extraction and grading by the computer. The control part adopts SCM to communicate with the computer to control the mechanical part. One of the advantages of this system is to adopt the closed light box to catch the strawberry image exacted. The other is to adopt two sensors and two switches to control the camera and the gripper.
(2) The strawberry colour is a very important index to sort. The Dominant Colour method fits to the human vision feeling, and increase the grading precision, so that it is adopted in a^* channel to sort the strawberry colour feature. Based on this method, three colour sorting indices were obtained.
(3) Because of the complex strawberry shape, the strawberry shape classification algorithm was the main focus of this paper. The *K*-means clustering method is the optimal algorithm in clustering analysis. According to the advance class centers, this *K*-means clustering method could put some similar class into one center. So it is very fast for this method to calculate and classify. In strawberry gradation, the strawberry shape is divided into four classes, i.e., there are four advance class centers. The 14 lines were drawn from one edge of strawberry to the other, and to be parameters of shape feature. The 14 lines were clustered to classify the strawberry into four classes. The largest fruit diameter was used to describe strawberry's size.
(4) In order to carry out one, two or three indices to grade the strawberry, the multi-attribute Decision Making Theory was introduced. It can assign different weight to different attributes of the object according to different standards to achieve the simplification of the multi-attribute problems. According to the grading require, the grading index and the weight of attribution were entered to realize the multi-attribute strawberry classification.
(5) In the laboratory, the mechanical part and control part were tested. The results show that the strawberry classification algorithm is designed viable and accurately. Strawberry size error is less than 5%, the colour grading accuracy rate is 88.8%, and the shape classification accuracy rate is over 90%. The average time to grade one strawberry is no more than 3 s.
(6) The strawberries in this automated grading system are put on the belt manually. In further researches, the strawberries could be transported automatically in order to improve the automation.

Conflict of interest

No conflict of interest.

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