# Online automatic grading of salted eggs based on machine vision

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**Abstract:** The quality of salted eggs differs in curing process. They need to be tested and graded before factory packaging. The dynamic images of salted eggs were acquired on conveyor. Firstly, preprocessing of color images must be done: the target area of the binary image was determined by mathematical morphology and removal of the object of a small area. According to the binary image is a convex or concave figure, the target region light leaked or not was determined. The effects of leaked region were eliminated by searching for mutation points, fitting salted egg boundary by the Least Square algorithm, labeling the binary image and extracting single target area. Then, six characteristic parameters were extracted in color space, and quality testing model was established by minimum error probability. The experimental results indicated that the detection accuracy reached above 93% and classification efficiency was 5400/h. It is proved the model is feasible for salted egg grading.

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## 1 Introduction

Salted egg is one of the traditional processing egg products in China. The egg quality directly affects the price of products. The price of first-class salted egg is several times higher than that of the secondary one. In order to ensure that qualified eggs are allowed to sell; unqualified eggs are blocked into market by factory itself to keep the quality. Grading salted eggs must be done to improve production efficiency. So far, salted egg grading mainly relies on manual work, which is heavy workload and single action. The workers are easily fatigue and productivity is low. Besides, due to the differences between people, different standards come into being[1-4]. Therefore, online automatic salted eggs grading system by machine vision[5] should be built. In this study, the problem was solved.

During a fresh duck egg curing, salt penetrates through egg shell, egg shell membrane and the yolk membrane from outside to inside[6-8]. Meanwhile, moisture in eggs exudes. In a fresh duck egg, salinity of the egg white significantly increases, but it does not increase too much in yolk; moisture in protein decreases slightly, and the water content of egg yolk drops significantly. Protein viscosity comes to be thinning, which is watery, transparent turbid liquid; the egg yolk viscosity increases significantly, which is a solidified shape, whose color is red or orange-red[9,10]. When a salted egg is nearly well-pickled, the concentration of sodium chloride outside is basically similar with the inside.

A salted egg quality is mainly determined by its

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contents. The non-destructive testing of contents is mainly evaluated through its translucence. As for the salted egg transparency, domestic and foreign experts have done a lot of researches: color space, wavelet analysis, texture analysis and so on.

In this study, color space method was applied and RGB\HSV models were used to extract six color characteristic parameters as the basis for analyzing the quality of salted eggs. Different qualities of salted eggs were graded by the pattern recognition.

## 2 Materials and methods

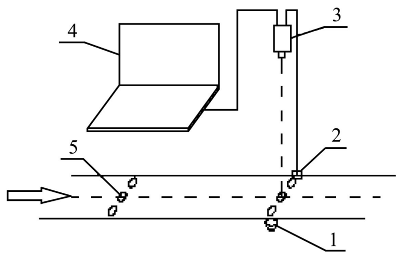
### 2.1 Materials

In this paper, the salted eggs were supplied by Hubei Shendan Healthy Food Co. Ltd. Although the quality standard of salted eggs is different in different countries, salted eggs can be graded into well-pickled eggs, desolvation eggs and spoilt eggs, according to specifications of bilateral trade agreements. Among these salted eggs, there were 297 well-pickled eggs, 207 desolvation eggs and 126 spoilt eggs.

### 2.2 Image acquisition

The quality grading system of salted egg was composed of mechanical transmission, PLC control system and machine vision system. And the machine vision system included LED light, sensor, industrial camera, computer and image acquisition card. As shown in Figure 1, industrial camera was set above salted eggs, and LED light was set beneath salted eggs. Sensor was set on the right side of conveyor belt. When three salted eggs in a row on conveyor, which was moving at the speed of 2.5 cm/s, were just below industrial camera and completely blocking the light source, a signal was sent to computer by sensor. Then computer sent an instruction to control industrial camera to capture color images of salted eggs. The image was shown in Figure 2. After analysis of images, the quality of salted eggs was determined.

The name of the industrial camera is UEyeRE, which works in 640×480 pixels 30 fps operation setting; its model is UI-2210RE-C-HQ. The sensor is diffuse photoelectric, whose name is F&C, and model is CR-10P. The LED light, model ZYG-L627, is a professional egg light. It can give out cold yellow visible light under the power of 1 Watt.




1. LED light 2. Sensor 3. Industrial camera 4. Computer 5. Salted eggs

Figure 1 Machine vision system for grading salted eggs

Figure 2 Color image of salted eggs

## 3 Preprocessing of images

### 3.1 Target area

When the color image of salted eggs was acquired, there was much surrounding environment information in it. The salted eggs pixels were what matters. Other parts must be deleted. Color image is 3-dimensional. In order to accelerate the speed of image processing[11,12], color images of salted eggs should be converted to binary images. The method of maximum between class variance which called OTSU was chosen as an automatic threshold method[13-14] to convert a intensity image to a binary image. Then the optimal threshold of the grayscale should be calculated. Finally, binary images by optimal threshold were obtained, as shown in Figure 3.

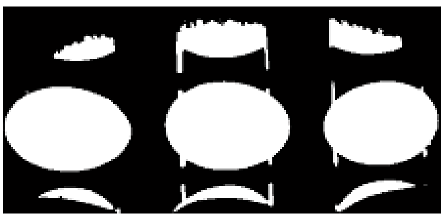


Figure 3 Binary image of salted eggs

The three middle salted egg images were the target area. There was some information about other rows in the binary images, which contained the light exposing from gap. This information had adverse effects on later processing, which needed to be removed. Three upper white arc-shaped regions showed where the front egg positions were because of no salted egg on the egg positions. These three lower white arc-shaped regions were the next row of salted eggs.

By analysis of irrelevant region, they were shown as arcs and lines in the image. Especially the straight strips, which were connected to salted egg pixels, could be regarded as burr. By erosion with the structural element ‘disk’, one of mathematical morphology, the effects of the burrs could be eliminated. If the number of pixels of an independent connected domain was less than 5 000, the domain was a salted egg image in the other rows or other independent irrelevant region. They could be removed by removal of the object of a small area. The result was shown in Figure 4.

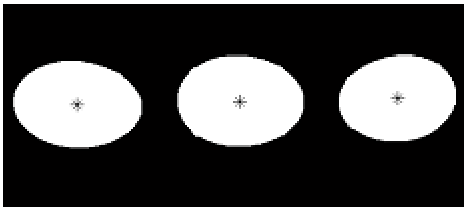
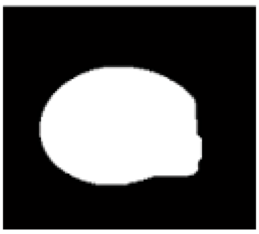


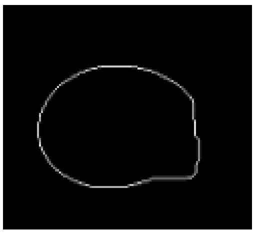
Figure 4 Convex image of salted eggs without light leakage

### 3.2 Light leakage around the target area

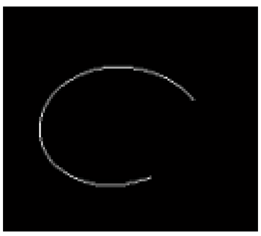
In the processing of image acquisition, a little light emitted by the LED light shined into the camera because some moving salted eggs failed to locate just above the light source. Corresponding processing must be done.



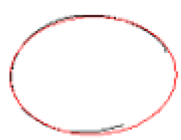
a. Leaked binary image



b. Leaked boundary image



c. Deleted leaked boundary image



d. Fitting image

Figure 5 Processing of light leakage

The salted egg image without light leakage was like an ellipse, which is a convex figure. While leaked region lay around the boundary of salted egg image, which made the image a concave figure. This was the key to determining whether the target area had light leakage.

Firstly, boundary of salted egg images should be extracted. Then the boundary must be smoothed to prevent misjudging the mutation points.

The top-left point of salted eggs boundary was chosen as a starting point. Then the code searched for the next boundary point counter-clockwise from left. When the next boundary point was found, the direction of next point was marked as the current exploration direction. And the next initial exploration direction was decided by rotating the current exploration 90 degrees clockwise. If the angle between the initial exploration direction and current exploration direction was less than 90 degrees, it turned out that the boundary was bulged. The coordinates of boundary bulged points should be recorded for post processing. The search should be repeated until the point searched went back the start point. The boundary between the first mutation point and the last mutation point should be deleted, which was caused by light leakage[15].

The general equation of an ellipse was

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \qquad (1)$$

The six element linear equation group:

$$\begin{cases} Ax_1^2 + Bx_1y_1 + Cy_1^2 + Dx_1 + Ey_1 + F = 0 \\ \quad\cdots\cdots \\ Ax_i^2 + Bx_iy_i + Cy_i^2 + Dx_i + Ey_i + F = 0 \\ \quad\cdots\cdots \\ Ax_n^2 + Bx_ny_n + Cy_n^2 + Dx_n + Ey_n + F = 0 \end{cases} \qquad (2)$$

where, $x$, $y$ were horizontal and vertical coordinates of boundary of no light leakage; $n$ was the number of boundary points; $A$, $B$, $C$, $D$, $E$ and $F$ were unknown parameters.

After converting equations into coefficient matrix, the parameters can be estimated by least square algorithm. The inner points of ellipse were the salted egg pixels.

### 3.3 Marking and segmentation of binary image

The binary image of salted eggs had three separate connected domains, which would be considered as a whole target by computer. Since each connected domain must be distinguished, image segmentation was needed. Labeling method was used to label the three separate connected domains from left to right. The result of the left connected domain, a salted egg, marked blue was shown in Figure 6.

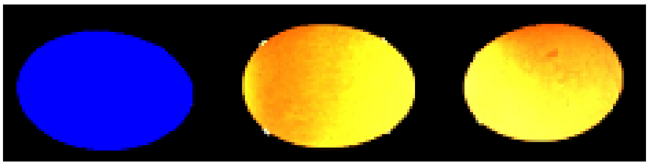
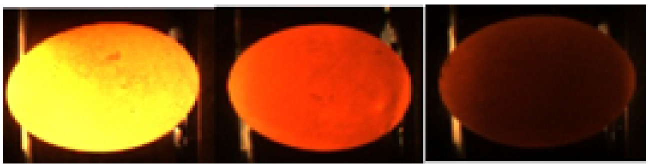


Figure 6 Image of the left salted egg marked

### 3.4 Extraction of characteristic parameters in color space

There is a variety of color space. RGB and HSV are common models[16].



a. A well-pickled egg b. A desolvation egg c. A spoilt egg

Figure 7 Images of different grade salted eggs

Through observing well-pickled eggs, desolvation eggs and spoilt eggs by breaking them, the fact was concluded as below. The protein of well-pickled eggs was watery, looking like transparent emulsion; the yolk was solidified shape, whose color was red or orange-red. Marinated for about 30 days, the chroma level of yolk increased from 4 to 7[17]. The color of images of well-pickled eggs was bright yellow because visible LED light passed through the protein. The color of images of desolvation egg was scarlet or red because protein got thicker, which looked like turbid liquid. The color character of desolvation egg depended on the color of yolk. The protein of spoilt eggs, which gave out a strong smell of hydrogen sulfide blend, was mushy, poorly mobile and almost opaque. The spoilt egg images showed poor transparency feature.

In this paper, six parameters were chosen as characteristic parameters in color space: red, green, blue, hue, saturation and value[18-19].

(1) Hue

$$H=\begin{cases}\frac{1}{6}\frac{G-B}{\mathrm{MAX}-\mathrm{MIN}}, & (R=\mathrm{MAX})\\ \frac{1}{6}\left(2+\frac{B-R}{\mathrm{MAX}-\mathrm{MIN}}\right), & (G=\mathrm{MAX})\\ \frac{1}{6}\left(4+\frac{R-G}{\mathrm{MAX}-\mathrm{MIN}}\right), & (B=\mathrm{MAX})\end{cases} \quad (3)$$

(2) Saturation

$$S=\frac{\mathrm{MAX}-\mathrm{MIN}}{\mathrm{MAX}} \quad (4)$$

(3) Value

$$V=\mathrm{MAX} \quad (5)$$

In these formulae, $R$, $G$, $B$, $H$, $S$ and $V$ represented the value of red, green, blue, hue, saturation and value, respectively. And

$$\mathrm{MAX}=\max[R, G, B] \quad (6)$$

$$\mathrm{MIN}=\min[R, G, B] \quad (7)$$

The mean values of characteristic parameters were shown in Table 1.

**Table 1 Mean values of characteristic parameters**

| SN | Red | Green | Blue | Hue | Saturation | Value |
|---|---|---|---|---|---|---|
| 1 | 249.4 | 85.78 | 6.253 | 0.055 | 0.974 | 249.4 |
| 2 | 251.4 | 124.5 | 17.03 | 0.077 | 0.932 | 251.4 |
| 3 | 251.1 | 97.18 | 16.4 | 0.059 | 0.934 | 251.1 |
| 4 | 248.2 | 118.7 | 16.13 | 0.075 | 0.935 | 248.2 |
| 5 | 251.8 | 124.4 | 15.5 | 0.078 | 0.938 | 251.8 |
| 6 | 251.6 | 141.1 | 21.71 | 0.088 | 0.913 | 251.6 |
| 7 | 251.2 | 149 | 20.34 | 0.096 | 0.918 | 251.2 |

Note: SN — Serial number of samples.

## 4 Grading model

### 4.1 Establishment of multiple linear regression equation of quality of salted eggs

It was difficult to determine which characteristic parameters contributed to the result of grading model most. SAS software was used to establish the discriminant function of multiple linear regressions.

It was supposed that

$$\begin{cases} z_0=\log(R)\\ z_1=\log(G)\\ z_2=\log(B)\\ z_3=\log(H)\\ z_4=\log(S)\\ z_5=\log(V)\\ y=\log(t)\end{cases} \quad (8)$$

Then, the discriminant function was

$$y=\beta_0 z_0+\beta_1 z_1+\beta_2 z_2+\beta_3 z_3+\beta_4 z_4+\beta_5 z_5+e \quad (9)$$

The $t$ value of well-pickled eggs was assigned to 300; and the $t$ value of desolvation eggs was assigned to 100.

These six characteristic parameters were put into the discriminant one by one by stepwise selection method. Then the selected parameter was determined whether it made contribution to the discriminant model and its significance. The non-significant parameters were excluded. The result showed that $R$, $B$ and $S$ made a greater contribution than $G$, $H$ and $V$ to the discriminant function. Thus, the discriminant function was concluded as below,

$$Y = R^{0.74093} \times B^{0.55311} \times S^{2.16047} \quad (10)$$

where, $Y$ was the value of linear regression.

### 4.2 Bayesian classifier based on minimum error probability

Minimum error probability was commonly used to select threshold automatically, which usually treated intensities of images as model features[20]. It was supposed that each intensity of model was an independently distributed random variable and the model obeyed a certain probability distribution. So the threshold that met minimum error rate can be calculated. There were only two objects in the image: the target and the background. The prior probability of them was $p_0(z)$ and $p_1(z)$, respectively; the mean values of them were $u_0$ and $u_1$, respectively.

The percentage rate of target pixels in total pixels was $w_0$. Then percentage rate of background pixels in total pixels was $w_1=1-w_0$. Mixed probability density was

$$p(z) = w_0 p_0(z) + w_1 p_1(z) \quad (11)$$

When $T$, the threshold, was selected, the probability of target pixels wrongly classified into background pixels was

$$e_0(T) = \int_T^{\infty} p_1(z)dz \quad (12)$$

The probability of background pixels wrongly classified into target pixels was

$$e_1(T) = \int_{-\infty}^{T} p_0(z)dz \quad (13)$$

Then the total error probability was

$$e(T) = w_0 e_0(T) + w_1 e_1(T) = w_0 e_0(T) + (1 - w_0) e_1(T) \quad (14)$$

The optimal threshold was the threshold that made the probability of total error the least.

Experiment data showed that upper desolvation eggs data were connected with lower well-pickled eggs data. Meanwhile the data of well-pickled eggs and desolvation eggs all separated from spoilt egg data. Transparency of spoilt eggs was clearly insufficient compared with others. As a result, it was easy to distinguish spoilt eggs from other grades. Therefore, the key point was how to distinguish well-pickled eggs and desolvation eggs.

The statistics data of well-pickled eggs and desolvation eggs were marked respectively. And the statistics data were arranged in increasing sequence. Then $T$ was assigned from the minimum data to the maximum data. At last, the testing egg would be determined to be a well-pickled egg if its statistics data were larger than $T$; otherwise, it was a desolvation egg. When the probability of the total error was minimum, $T$ was the optimal threshold. By calculating the probability of this test total error, the optimal threshold $T$ was 199, which was close to the mean of well-pickled eggs' expectation, 300, and desolvation eggs' expectation, 100. This result verified the reliability of the model.

Discrimination result was concluded as below.

When $R$ component of testing salted eggs was less than 100, it was determined to be spoilt eggs.

When $R$ component of testing salted eggs was larger than 100, $Y$ was calculated:

$$Y = R^{0.74093} \times B^{0.55311} \times S^{2.16047} \quad (15)$$

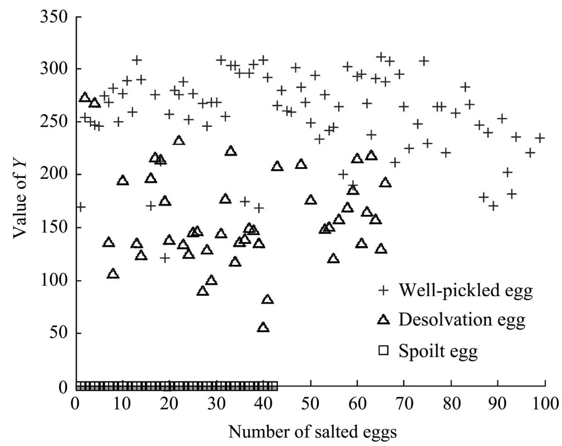



Figure 8 Scatter image of value of $Y$

When $Y \geqslant 199$, the salted eggs determined to be well-pickled eggs.

When $Y \leqslant 199$, the salted eggs determined to be desolvation eggs.

### 4.3 Model verification

Well-pickled egg, desolvation egg and spoilt egg samples were selected. Firstly, they were graded and marked carefully by manual work. Then all salted eggs were mixed together and placed on online grading system randomly to be tested. After completion of testing, the number of right judgments and the number of wrong judgments would be counted. The statistics were shown in Table 2 as below.

**Table 2 Results of salted egg quality grading system**

| Salted egg categories | $N$ | $R$ | | | |
|---|---|---|---|---|---|
| | | $G$ | | | $\eta$ |
| Well-pickled egg | 297 | 276 | 21 | 0 | 93% |
| Desolation egg | 207 | 21 | 186 | 0 | 90% |
| Spoilt egg | 126 | 0 | 3 | 123 | 97% |

Note: $N$ - Number of samples; $R$ - Result of salted egg quality grading system; $\eta$ - Recognition rate; G -Grading result

Bayesian classifier based on minimum error probability was more stable and faster than artificial neural network, and was more accurate than minimum risk Bayesian. In addition, it was easier to establish sorting model than $K$ means clustering.

The correct rate of automatic grading of salted egg quality method was 93% by minimum error probability.

## 5 Conclusions

1) It was a research on the method of salted egg grading according to quality. Mechanical systems were improved; PLC control system and machine vision system and assembled salted egg quality grading system were designed. This system graded salted eggs into well-pickled eggs, desolation eggs, spoilt eggs according to their quality.

2) Six color characteristic parameters were extracted from test salted egg image in color space by building multiple linear regression equation. The correct rate was 93%. The efficiency of system was 5 400 eggs per hour.

3) The thickness and transparency of egg's shell, the color of eggshell, and whether a testing egg was clean all reduced accuracy of the sorting model.

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