Application of Hyperspectral Images and Spectral Features of Yolks in Egg Freshness Detection

Shiqi Huang†*, Xuewen Pu† and Peng Luo†

† School of Information Engineering, Xijing University, Xi’an, 710123 China
*Corresponding author’s e-mail: 2752944956@qq.com

Abstract. The detection of egg freshness is an important basis and means to obtain the effective value of eggs. In order to more effectively and reasonably classify and monitor the quality of eggs, a new egg quality identification method based on the hyperspectral image data of egg yolk and its spectral characteristics data is proposed. In this method, the spectral and hyperspectral data of the raw yolk and the boiled yolk are obtained by using a spectrometer and a hyperspectral imager, respectively. By analyzing different spectral properties, building a relationship model between each other, combining with different results, the new proposed method has achieved the purpose of identifying the freshness of eggs. The test experiments were carried out with different batches eggs of the same type. The results show that the method proposed in this paper can detect the freshness of eggs, and can provide new ideas and references for egg quality classification and detection.

1. Introduction

The identification of egg quality and freshness is a very meaningful thing, which involves food safety and social stability. For a long time, the identification of egg freshness, for people, is mainly realized by physical methods, such as candling, knocking, weighing and measuring. It is very obvious that the test results are greatly influenced by subjective factors. Therefore, it is great practical significance to develop new testing theories, methods and technical equipment for identifying the freshness and quality of eggs. In recent years, with the rapid development of modern agriculture and food industry, the testing technology and the level of agricultural products and food are gradually increasing. In addition to the traditional physical detection methods, many scholars put forward many new detection techniques and methods based on the characteristics of eggs. These methods are mainly based on non-destructive testing by instruments[1-10]. For example, Abdullah et al. proposed using the visible and support vector machine to detect the egg freshness[1]. They firstly obtained the image features of eggs, and then used the support vector machine to classify eggs for detecting their freshness. Wang et al. used the computer vision and BP neural network technology to detect the egg freshness, and got good results[2]. Zhao et al. utilized the near-infrared spectroscopy, combined with support vector machine and detected the egg freshness[3], and the detection accuracy of egg freshness was 93.3%. Priyadumkol et al. proposed the method of image processing to detect the crack of the unwashed eggs[4], and the detection rate reached 94%. Soltani et al. detected the freshness of eggs by using the method of dielectric constant and machine learning, and good results were got[5]. Sun et al. used the dielectric properties of eggs, combining the support vector machine, kernel function and the optimization algorithm, performed the detection of egg quality and achieved good classification effect [6]. Jin et al. used the acoustic characteristics of eggs to detect the cracks of eggs, and the recognition rate was more than 90% [7]. Li used the multiple linear regressions and the BP neural network to
establish the relationship model between electronic nose response signals and egg physical and chemical indexes, and the freshness of eggs was detected [8]. Li et al. adopted the electronic nose technology and combined with chemical methods to detect the storage time of eggs and the index of egg yolk, and the effect was very good [9]. Hyperspectral remote sensing is a new generation of photoelectric detection technology, which integrates the advantages of spectral detection and image detection, and realizes the union of imagery and spectrum. The typical feature of hyperspectral imaging is to obtain spectral information with high resolution, so that many problems that cannot be solved in the panchromatic and multi-spectral images have become very easy. Therefore, it has been applied widely in many fields such as remote sensing, archaeology, agriculture, food security, public security and military [10-14]. Zhang et al. obtained hyperspectral data of eggs and used the continuous projection algorithm to extract characteristic wavelengths for detecting the egg freshness [14], which was a useful attempt. These methods all describe the egg freshness or quality parameters from different angles, thus describing the quality of eggs.

Hyperspectral imaging technology realizes the combination of spectral characteristics and spatial information, so it is an important means to detect material composition and type identification. Hyperspectral image data measures the spectral characteristics of the material from the surface angle; the spectral characteristic data measures the material properties from the point angle, and they have their own advantages. The new detection method of egg freshness in this paper combines the characteristics of hyperspectral image and spectral feature. The main contributions of this article include three aspects. The first is to put forward the fusion idea of different spectral characteristics, so more accurate information can be obtained. The second is to use the spectral characteristics of the raw yolk and the boiled yolk to discuss the freshness of the egg, which is not dependent on the characteristic parameters of the egg. The third is to fuse the spectral features of different detection methods and different forms of egg yolks to determine the egg freshness.

2. Experimental preparation and data acquisition
The Analytical Spectra Devices (ASD) FieldSpec3 spectrometer was used to obtain the spectral characteristics of egg yolks. Before using this instrument, the spectrometer needs a preheat treatment and the preheating time was about 15 minutes. The spectral range of the FieldSpec3 was 350 nm-2500 nm, and the spectral resolution included two values. It is 3nm and 10nm from 350nm to 1000nm and from 1000nm to 2500nm, respectively. When the data acquisition process was carried out, the sampling number of every measurement point was 100 times, and then their average value was taken as the result of the measurement. Different measuring points were set, with the number generally not less than 50, to ensure that each egg yolk had more than one measurement point. Finally, the sum and average operation were performed on the data of all measurement points, and the result was the final measurement result of the spectral characteristic of the yolk.

The hyperspectral imaging instrument is called the MHyperSIS system. The imaging wavelength range of the system was 400nm-2500nm, and the system consisted of two lenses, which corresponded to two imaging bands, namely 400nm-1000nm and 1000nm-2500nm, with spectral resolutions of 2.8nm and 10nm, respectively. Since there was little difference among data in the shortwave and infrared band, we chose the wavelength range from 400nm to 1000nm in this experiment to obtain the hyperspectral image data, and the size of an image of each band was 1344 × 1024. The hyperspectral image data cube contained spectral characteristics, so the spectral characteristic data were extracted from the hyperspectral data. The hyperspectral image data were opened, and the spectral characteristics of multi-points were extracted. Usually, the average value of each yolk was at least five points, and the average value was taken as the final spectral characteristic curve data and saved.

3. Algorithm description
The proposed detection method of egg freshness based on spectral characteristics of yolks in this paper is different from other general non-destructive testing methods based on the spectral features or the hyperspectral image. This method not only includes data acquisition with different instruments, but it
also contains different forms of yolks. Due to the fusion of different data types and different methods, the reliability of the results is strong. This method does not need to rely on other physical or chemical parameters to detect and describe the freshness of eggs, and its principle flow chart is shown in Fig. 1.

![Flow chart of the new algorithm.](image)

The main steps of the new method included the following.  
(1) The eggs were prepared for the experiments. The eggs selected here belong to the same type, but the storage time was different. The number of each batch of eggs was 260, and all eggs were cleaned. After washing and drying, they were divided into two groups, with 130 eggs in each group.  
(2) Get the boiled egg yolks and the yolks of raw eggs.  
(3) The spectral characteristic data of egg yolks were measured. The boiled yolks and the raw yolks were measured with the FieldSpec3 spectrometer and the hyperspectral imager, their spectral data were obtained, and then these data performed the related pretreatment operations.  
(4) Analysis and modelling of the spectral characteristic data of egg yolks were performed. By means of different instruments, the spectral characteristic data of yolks were obtained in different ways. The egg freshness was discussed from the different angle of boiled yolks and raw yolks.  
(5) The freshness of eggs was predicted and determined. Apart from the analysis of the freshness of the egg from the angle of the spectral characteristic curve model, some corresponding parameters were also used to further illustrate the quality of eggs; for example, the similarity and Euclidean distance between different yolks and different instruments were used.

4. Experimental results and analysis

4.1. Experiments on the first batch of eggs
The brands of eggs from Shaanxi village were selected to perform the experiments, and they were obtained at the supermarket. The experimental eggs were obtained in two batches, and the experiment was carried out according to the experimental process described in section 3. The experimental results were shown in Fig.2 and Fig.3. There were four different experimental processes. Namely, the spectral characteristic curve data of the raw yolk and the boiled yolk were directly measured by the spectrometer, and the hyperspectral characteristic data of them were obtained with the hyperspectral imager. All data performed the pre-processing and normalization operations. The experimental results of the first and the second batch of eggs were shown in Fig.2 and Fig.3, respectively.
Fig.2(a) shows that the data curves obtained by the hyperspectral imager are flat, but the data curves obtained by the spectrometer are much more volatile. The reason for this difference is that the hyperspectral imager obtains data from a region, while the spectrometer obtains data from a point location. The spectral characteristic curves of raw yolk shown in Fig.2(b) and Fig.2(c) were obtained by different instruments. Here, Fig.2(b) gives the original measurement values, and Fig.2(c) provides the data after the rearrangement of the spectrum. It is known from Fig.2(b) that the data obtained by the hyperspectral imager are relatively flat and the reflection value is higher. However, there are some intersections between the two curves in the visible band. To further illustrate their relationship, spectral reordering was used to study their relationship. When the spectral characteristic curves are approximately similar in shape, reflection value or change trend, it is rather difficult to extract the different spectral characteristics from different objects in the original spectrum data. To help with the extraction of the spectral features of the ground objects, spectral rearrangement can be used to enhance the spectral difference between different objects. The spectral rearrangement breaks the order of the spectrum arrangement according to the order of wavelength, and they are rearranged according to the size of the spectral reflectance value of each band. Assume there is a spectral characteristic curve \( r \), here \( r=(r_1,r_2,...,r_L) \), which is as an example that illustrates the basic principle of spectral rearrangement. Here, \( r \) is a spectral vector, and \( L \) is the band number of the spectral curve. With \( r \) as the base spectrum, the values of \( r_1, r_2, ..., r_L \) are rearranged in order of smallest to largest, and the spectral characteristic curves after reordering are obtained, represented by \( r^*, r^*=(r_{k1},r_{k2},...,r_{kL}) \). Here, \( k \) is the serial number after rearrangement and it satisfies the following conditions.

\[
i < j, r_i < r_j \tag{1}
\]

The spectral rearrangement can not only be carried out in the order of smallest to largest but also in the order of largest to smallest. After the rearrangement of the spectrum, some of the spectral characteristics can be distinguished. Note that after the rearrangement of the spectrum, the values of the wavelengths in the coordinate axis do not necessarily correspond to the true values. That is, the wavelength value of the abscissa corresponding to the reflection value of the spectral characteristics is not the actual value. Fig.2(c) is the result of the rearrangement of Fig.2(b) in accordance with the reflected value from smallest to largest. It is observed in Fig.2(c) that the difference between spectral characteristic curves obtained by different instruments is relatively large. The spectral characteristic obtained by the hyperspectral imager are larger and flatter than that obtained by the spectrometer.

4.2. Experiments on the second batch of eggs
The same experiment was carried out on the second batch of eggs, and the results are shown in Fig.3. It is observed that the biggest difference between Fig.2 and Fig.3 is the spectral characteristic curve of raw yolk. The spectral characteristics of the raw yolk obtained by the spectrometer and the hyperspectral imager show almost no difference, as observed in Fig.3(a) and Fig.3(b). Another large difference is that in the first group of experiments, the value of the data obtained by the hyperspectral imager was larger than the value obtained by the spectrometer, whether the data were for the raw yolk or the boiled yolk. However, in the second group of experiments, while the spectral characteristics of the boiled yolk still followed this pattern, the raw yolk did not, with the spectral data measured by different instruments intersecting, as shown in Fig.3(b) and Fig.3(c). For this reason, after
rearrangement of the mixed measurement results of different instruments or the mixed measurement results of different forms by the same instrument, the spectral characteristic curves also show the cross phenomenon.

![Figure 3. Test results of the second batch of eggs.](image)

4.3. Quantitative analysis of parameters

To further explain the spectral characteristics of egg yolks, the parameters of the egg yolks were selected for quantitative analysis. The two parameters selected in this experiment were similarity and Euclidean distance. The similarity reflects the degree of similarity between them, and the Euclidean distance reflects the difference between them in the spectral reflectance value.

Suppose there are two spectral characteristic curves \( r_k \) and \( r_l \), \( r_k = (r_{k1}, r_{k2}, \ldots, r_{kL}) \), \( r_l = (r_{l1}, r_{l2}, \ldots, r_{lL}) \).

The similarity between these two curves is expressed by the correlation coefficient, and the mathematical formula is as follows.

\[
C_{kl} = \frac{\sum_{i=1}^{L} (r_{ki} - \mu_k)(r_{li} - \mu_l)}{\sqrt{\sum_{i=1}^{L} (r_{ki} - \mu_k)^2 \cdot \sum_{i=1}^{L} (r_{li} - \mu_l)^2}}
\]  

Here the variable \( C_{kl} \) represents the correlation coefficient; \( k \) and \( l \) represent two different spectral characteristic curves; \( L \) is the number of bands; \( \mu_k \) and \( \mu_l \) are the mean values of the spectral characteristic curves of the \( k \)th and the \( l \)th band, respectively; and \( r \) denotes the normalized spectral characteristic reflection value. A greater correlation coefficient means they are more similar.

The Euclidean distance is usually used to express the relationship between two variables. The larger the value is, the greater the difference between them; the smaller the value is, the smaller the difference between them. Here, the difference of the reflection values between two spectral characteristic vectors is described by the Euclidean distance, and the mathematical model is as follows.

\[
D_{kl} = \sum_{i=1}^{L} (r_{ki} - r_{li})^2
\]

Here \( k \) and \( l \) represent two different spectral characteristic curves, \( L \) denotes the number of all bands, \( r \) is the normalized reflection value of the spectral characteristic, and \( D_{kl} \) represents the distance between the spectral characteristic curves of the \( k \)th and the \( l \)th band.

To better illustrate the characterization of similarity and Euclidean distance parameters, some parameters and variables were explained first, as shown in Table 1. The similarity and Euclidean distance considered here were not the values between the single spectral characteristic curves, but they were the values calculated after the combination. For example, \( C_{11} \) represents a measure of similarity between the data obtained by the spectrometer and the hyperspectral imager; for other parameters refer to Table 1. The computing results of the original spectral data and the data after spectral rearrangement are shown in Table 2 and Table 3. In Table 3, \( C_{11}^*, C_{22}^* \), \( D_{11}^* \) and \( D_{22}^* \), indicate the correlation coefficients and distances after the spectral rearrangement, respectively. Their physical meaning corresponds to parameters \( C_{11} \), \( C_{22} \), \( D_{11} \), and \( D_{22} \).

Table 2 and Table 3 show that the correlation coefficient of the original data is smaller than that of the spectrum rearrangement, but the distance parameter value of the original data is larger than that of the spectrum rearrangement. In the original data, \( C_{11} > C_{22} \), but after the rearrangement of the spectral data, it becomes \( C_{11}^* < C_{22}^* \). Whether it is the original data or the data after the spectrum
rearrangement, the change of their corresponding difference is small; for example, $|C_{11} - C_{22}|$ and $|C'_{11} - C'_{22}|$. As observed in Table 2, if the value between $|C_{11} - C_{22}|$ and $|D_{11} - D_{22}|$ is smaller, the quality of the batch of eggs is closer, and the quality is better. This conclusion is consistent with the laws reflected in Fig. 2 and Fig. 3, and it also shows that the quality of the second batch of eggs was superior to the first batch.

5. Conclusion
In this study, the spectral characteristics of raw and boiled yolks were measured by spectrograph and hyperspectral imager, and effective experimental results were obtained. Through processing and analysis of the experimental data, some useful conclusions were drawn. If the spectral characteristic curves of egg yolk measured in different ways are similar, the freshness of the egg is good and the egg quality is high. Similarly, if the parameter values, such as the similarity and Euclidean distance, are used to express the quality of eggs, a smaller absolute difference between these parameters obtained in different ways means a better egg quality. The new method of egg quality identification proposed in this paper is effective and was verified by measured data. The new method provides a novel concept and method for egg quality identification and has certain application and reference values.

| Name | Instructions |
|------|--------------|
| $r_1$, $r_2$ | Spectral characteristics of raw and boiled yolk by the spectrometer, respectively |
| $r_3$, $r_4$ | Spectral characteristics of raw and boiled yolk by hyperspectral imager, respectively |
| $C_{11}$, $C_{22}$ | The correlation coefficient between $(r_1 + r_2)$ and $(r_3 + r_4)$, $(r_1 + r_3)$ and $(r_2 + r_4)$, respectively |
| $D_{11}$, $D_{22}$ | The Euclidean distance between $(r_1 + r_2)$ and $(r_3 + r_4)$, $(r_1 + r_3)$ and $(r_2 + r_4)$, respectively |

| Name or type | $C_{11}$ | $C_{22}$ | $D_{11}$ | $D_{22}$ |
|--------------|---------|---------|---------|---------|
| The first batch of eggs | 0.9123 | 0.8650 | 7.0574 | 4.1160 |
| The second batch of eggs | 0.9068 | 0.8930 | 4.3232 | 5.0044 |

| Name or type | $C'_{11}$ | $C'_{22}$ | $D'_{11}$ | $D'_{22}$ |
|--------------|---------|---------|---------|---------|
| The first batch of eggs | 0.9707 | 0.9864 | 6.8921 | 3.0103 |
| The second batch of eggs | 0.9755 | 0.9855 | 3.6242 | 4.1385 |

Acknowledgments
The work was supported by Natural Science Foundation of China (No.41574008, 61379031, 61673017, 61905285), Natural Science Key Basic Research Plan in Shaanxi Province of China (No. 2020JZ-57), the Special Foundation for Special Talents of Xijing University (No. XJ17T04).

References
[1] M. H. Abdullah, S. Nashat, S. A. Anwar, et al., “A framework for crack detection of fresh poultry eggs at visible radiation,” Computers and Electronics in Agriculture, vol. 141, pp.81-95, 2017.
[2] Q. H. Wang, Y. L. Ren, Y. X. Wen, “Study on nondestructive detection method for fresh degree of eggs based on BP neural network,” Transactions of the Chinese Society for Agricultural Machinery, vol. 37, pp. 104-106, 2006.
[3] J. W. Zhao, H. Lin, Q. S. Chen, et al., “Identification of egg's freshness using NIR and support vector data description,” Journal of Food Engineering, vol. 98, pp. 408-414, 2010.
[4] J. Priyadumkol, C. Kittichaikarn, S. ThainimitCrack, “Detection on unwashed eggs using image processing,” Journal of Food Engineering, vol. 209, pp. 76-82, 2017.

[5] M. Soltani, M. Omid. “Detection of poultry egg freshness by dielectric spectroscopy and machine learning techniques,” LWT - Food Science and Technology, vol. 62, pp. 1034-1042, 2015.

[6] J. Sun, B. Liu, H. P. Mao, et al., “Non-destructive identification of different egg varieties based on dielectric properties,” Food Science, vol. 38, pp. 282-286, 2017.

[7] C. Jin, L. J. Xie, Y. B. Ying, “Eggshell crack detection based on the time-domain acoustic signal of rolling eggs on a step-plate,” Journal of Food Engineering, vol. 153, pp.53-62, 2015.

[8] J. T. Li, J. Wang, Y. Li, Y. Wei, “Detection of egg freshness using electronic nose,” Modern Food Science and Technology, vol. 33, pp. 300-305, 2017.

[9] J. Li, S. S. Zhu, S. Jiang, et al., “Prediction of egg storage time and yolk index based on electronic nose combined with chemometric methods,” Food Science and Technology, vol. 82, pp. 369-376, 2017.

[10] Y. Z. Feng, D. W. Sun, “Application of hyperspectral imaging in food safety inspection and control: a review,” Critical Reviews in Food Science and Nutrition, vol. 52, pp. 1039-1058, 2012.

[11] D. Liu, D. W. Sun, X. A. Zeng, “Recent advances in wave length selection techniques for hyperspectral image processing in the food industry,” Food and Bioprocess Technolog, vol.7, pp. 307-323, 2014.

[12] J. Shan, X. Wang, M. Russel, et al.,“Comparisons of fish morphology for fresh and frozen-thawed crucian carp quality assessment by hyperspectral imaging technology,” Food Analytical Methods, vol. pp. 1-10, 2018.

[13] J. Shi, W. Chen, X. Zou, et al., “Detection of triterpene acids distribution in loquat leaf using hyperspectral imaging,” Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, vol. 188, pp.436-442, 2018.

[14] W. Zhang, L. Q. Pan, H. Y. Lin, “Nondestructive detection on freshness of eggs with hyperspectral imaging technology,” Journal of NanJing Xiao Zhuang University, vol. 6, pp. 46-50, 2015.