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Non-destructive internal quality assessment of eggs using a synthesis of hyperspectral imaging and multivariate analysis

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A B S T R A C T

The study develops a nondestructive test based on hyperspectral imaging using a combination of existing analytical techniques to determine the internal quality of eggs, including freshness, bubble formation or scattered yolk. Successive projections algorithm (SPA) combined with support vector regression established a freshness detection model, which achieved a determination coefficient of 0.87, a root mean squared error of 4.01%, and the ratio of prediction to deviation of 2.80 in the validation set. In addition, eggs with internal bubbles and scattered yolk could be discriminated by support vector classification (SVC) model with identification accuracy of 90.0% and 96.3% respectively. Our findings suggest that hyperspectral imaging can be useful to non-destructively and rapidly assess egg internal quality.

1. Introduction

Eggs are nowadays transported considerable distances (often 200–500 km in China), and stored before they are used. Egg freshness is negatively correlated with storage time (Liu and Tu, 2012), and the unavoidable vibration in the transportation sometimes results in scattered yolk and air bubbles. All these damaged eggs are unacceptable by consumers, the food industry, and especially for farmers using it for hatching of chicks. The current quality assessment is largely performed using eye-inspection of egg defects. This is practical to examine egg appearance (Cattaneo et al., 1997), however, the internal defects of eggs, such as scattered yolk, air bubbles, and staleness, are difficult to be identified by human eyes. This method is called "candling" and involves a person looking at eggs on top of bright light shining through each egg on a conveyor belt. It is a tiring process and can lead to many mistakes. Therefore, a rapid, objective and non-destructive technique is needed to improve the internal quality inspection of eggs.

The reduction of egg freshness can be explained by the structural changes of ovomucin–lysozyme interaction. These structural changes result in a thin layer of egg white, and an increase of gas exchanges with the ambient conditions through the shell pores (Stadelman and Cotterill, 1995). Near infrared reflectance (NIR) spectroscopy has been widely used to detect structural changes (Klaypradit et al., 2011; Stubbs et al., 2009). Giunchi et al. (2008) reported a combination of FT-NIR and partial least square regression (PLSR) to assess egg freshness. A predictive model of Haugh unit (a measure of egg quality based on the height of its egg white) was developed with a determination coefficient (R^2) being 0.676. Zhao et al. (2010) applied a combination of NIR spectroscopy and support vector data description (SVDD) to resolve the imbalance in egg sampling when the number of fresh eggs is much larger than that of deteriorated ones. The identification rate was 93.3% in both fresh egg and deteriorated egg groups. However, the data obtained from NIR spectroscopy consist of overlapping information (Kamruzzaman et al., 2012). Therefore, it is necessary to reduce uncorrelated components, and to augment feature extraction. Lin et al. (2011) attempted to use principal component analysis

Abbreviations: NIR, near infrared reflectance; HU, Haugh unit; ROI, region of interest; PCA, principal component analysis; MSC, multiplication scatter correction; ICA, independent component analysis; SPA, successive projection algorithm; GLCM, gray level co-occurrence matrix; PLSR, partial least square regression; SVM, support vector machine; SVR, support vector regression; SVC, support vector classification; RPD, ratio of prediction to deviation; RMSEC, root mean square error of calibration; RMSEP, root mean square error of prediction; $R^2{}_c$, coefficient of determination of calibration; $R^2{}_p$, coefficient of determination of prediction; RGB, Red Green Blue; HSV, Hue saturation value.

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(PCA) and independent component analysis (ICA) to extract features from egg spectra. The correlation coefficient (R) was 0.879 for the predictive model of egg freshness. These reports suggest that NIR spectroscopy might be applicable to assess the freshness of eggs. However, the wavelength of NIR spectroscopy for the freshness assessment of eggs has not been optimized in the literature.

Egg internal defects, such as scattered yolk and air bubbles, caused by physical forces but have not yet resulted in any chemical changes may not be able to be detected by the NIR spectroscopy. Image analysis, in the red–green–blue color space, can provide spatial information of objects, and have been utilized to evaluate egg quality, such as crack and dirt on eggshell (Li et al., 2012; Mertens et al., 2005). Since imaging techniques do not contain spectral information, common computer vision is mainly applied to monitor external attributes (shape, color, size and external defects) rather than internal quality. Dehrouyeh et al. (2010) applied a computer vision system to detect internal blood spots in eggs, resulting in 91% accuracy of blood spot detection. However, an imaging technique designed to detect scattered yolk, and internal bubbles is still absent from the literature.

Hyperspectral imaging combines the advantages of imaging and spectroscopy, and can acquire spectral and image information simultaneously in one system. Its rich spectral information is sufficient for internal feature extraction (Wu et al., 2012). Hyperspectral imaging has been applied to assess the quality of meat (ElMasry et al., 2013; Barbin et al., 2012), fruit (Li et al., 2011), vegetables (Rady et al., 2014; Lu and Ariana., 2013) and eggshell cracks (Lawrence et al., 2008).

In this study, hyperspectral imaging was attempted to assess egg internal quality. For this purpose, the research was conducted through (1) to develop a hyperspectral imaging system, and optimize its effective wavelength to calibrate Haugh unit (indicating egg freshness) determination; (2) to extract hyperspectral image features, and apply them to identify egg internal bubbles; (3) to establish an image segment algorithm in order to extract yolk characteristics for scattered yolk detection; (4) to build robust models for the inspection of egg internal defects.

2. Material and methods

The procedures of imaging analysis are outlined in Fig. 1, including image acquisition, analytical measurement of internal quality attributes, spectral analysis, image processing, and pattern recognition. The details are described in the following sections.

2.1. Sample collection

Six hundred and forty-five white shell eggs were produced by noble concubine hens at a local poultry farm in Nanjing, China. The eggs were divided into 3 sets. The eggs in set 1 ($n = 245$) were stored at 20 °C (about 50% of relative humidity) for 0, 7, 14, 21, 28, 35 and 42 days to detect freshness (Haugh unit). The eggs in set 2

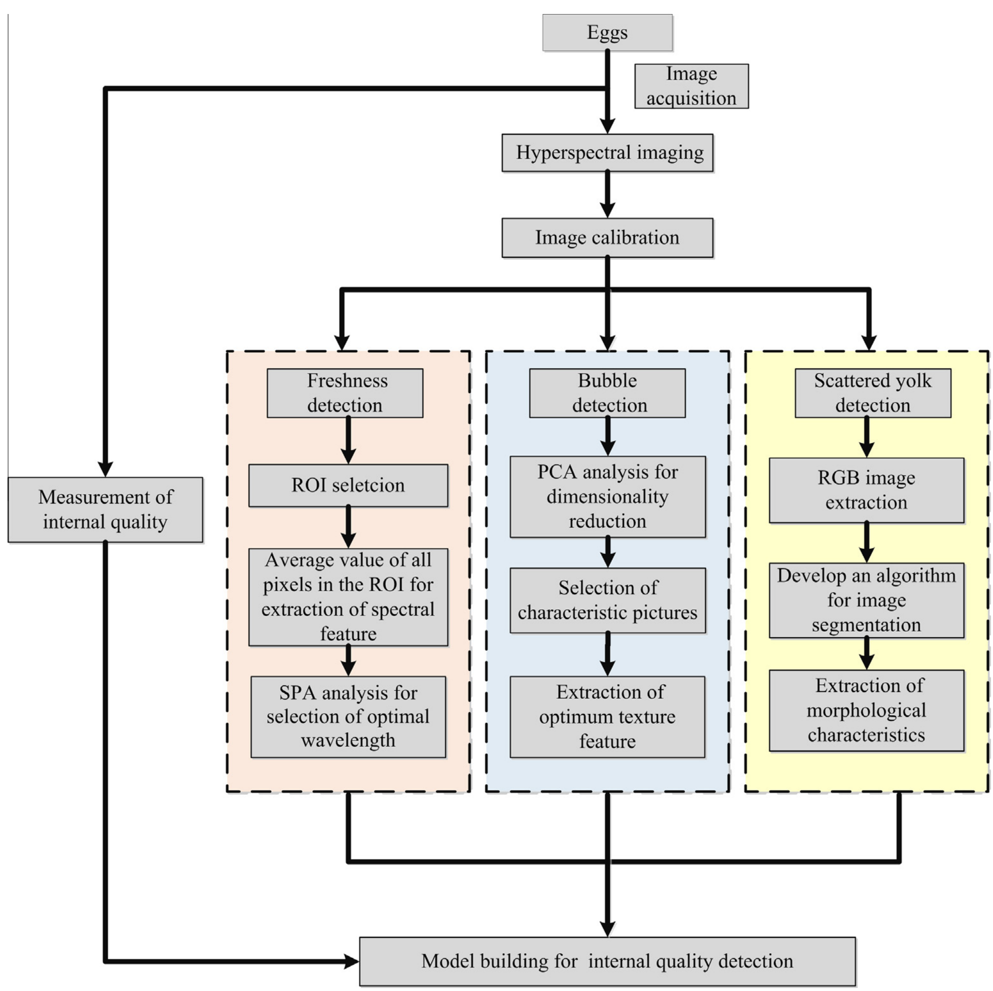

Fig. 1. Experimental procedures.