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Feasibility study on nondestructively sensing meat's freshness using light scattering imaging technique

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ABSTRACT

Rich nutrient matrix meat is the first-choice source of animal protein for many people all over the world, but it is also highly susceptible to spoilage due to chemical and microbiological activities. In this work, we attempted the feasibility study of rapidly and nondestructively sensing meat's freshness using a light scattering technique. First, we developed the light scattering system for image acquisition. Next, texture analysis was used for extracting characteristic variables from the region of interest (ROI) of a scattering image. Finally, a novel classification algorithm adaptive boosting orthogonal linear discriminant analysis (AdaBoost–OLDA) was proposed for modeling, and compared with two classical classification algorithms linear discriminant analysis (LDA) and support vector machine (SVM). Experimental results showed that classification results by AdaBoost–OLDA algorithm are superior to LDA and SVM algorithms, and eventually achieved 100% classification rate in the calibration and prediction sets. This work demonstrates that the developed light scattering technique has the potential in noninvasively sensing meat's freshness.

1. Introduction

Pork meat is a precious, nutritious, and universal food commodity in human diet, which has been widely demanded and consumed all over the world (Grunert, Verbeke, Kügler, Saeed, & Scholderer, 2011; Li, Chen, Zhao, & Ouyang, 2014; Pereira & Vicente, 2013). Due to the growing number of meat quality and safety incidents, increasing attention has been paid by consumers and manufacturers to this problem (Trienekens & Zuurbier, 2008). The globalization of meat commerce, and the logistics of distribution from processing centers, makes it difficult to ensure meat freshness (Arihara, 2006). During transportation and preservation, it is inevitable that spoilage happens, which is a complex dynamic process owing to the reactions of tissue enzymes and chemical reactions such as oxidation (Huang, Zhao, Chen, & Zhang, 2014). In the process of spoilage, nutrition components (carbohydrate, fat, protein, etc.) in pork meat gradually decompose, producing some small toxic molecular components (organic acids, fatty acids, ammonia, etc.) (Huang et al., 2014; Li, Chen, Zhao, & Wu, 2015). From the viewpoint of meat quality and safety, it is therefore, of great significance to evaluate meat freshness before making them available to consumers.

The current standard detection methods are conventionally physico-chemical or biological methods, which are not only destructive, time-consuming, laborious and require lengthy sample preparation, but also not competent with modern industrial processing technologies, and consequently unsuitable for online monitoring (Prieto, Roehe, Lavín, Batten, & Andrés, 2009). In addition, false detection or diagnosis of such stale meat may lead to food safety incidents. Several methods that are in development are aiming for non-destructive, rapid, reagentless, and still accurate and sensitive detection. Fourier transform near infrared (FT-NIR) spectroscopy (Cai, Chen, Wan, & Zhao, 2011), hyperspectral imaging (Chen, Zhang, Zhao, & Hui, 2013; Huang, Zhao, Chen, & Zhang, 2013; Kamruzzaman, Sun, ElMasry, & Allen, 2013) and electronic nose (Chen, Hui, Zhao, & Ouyang, 2014; Papadopoulou, Panagou, Tassou, & Nychas, 2011), are widely being investigated for meat quality detection. These developing methods are an improvement in that they are non-destructive, can be real-time, and have the potential to be used as an on-site detection method. However, most of these methods still need trained personnel to operate and can be expensive due to the requirement of specific instrumentation.

In the last few decades, there has been increasing attention on light scattering technology (Mensch, Davis, & Blue, 2015). Light scattering instruments such as surface plasmon resonance (SPR), flow cytometry and so on, have enabled the research of various biological molecules and ultimately have been a commercial success (Nebe-von-Caron, Stephens, Hewitt, Powell, & Badley, 2000; Perkins & Squirrell, 2000). Moreover, an emerging technology in laser optical sensors, which was based on the concept that variations in refractive indices and size, relative to the arrangement of cells in bacterial colonies growing on a semi-solid agar surface will generate different light scatter patterns, has been studied in combination with chemometrics, and achieved good performances (Bae et al., 2007; Banada et al., 2007; Peng et al.,

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2011). In addition, hyperspectral imaging modified with a point light source was widely used for the determination of meat quality, such as total viable count, tenderness, juiciness and so on (Tao & Peng, 2014; Wu et al., 2012). Light scattering within meat was reported to be subject to the effects of viable counts in meat and muscle structural properties such as sarcomere length and collagen content. During meat spoilage, these meat parameters are the primary mechanisms controlling meat quality, and so the scattering information within meat samples can be expected to give good prediction for meat freshness. However, the laser optical sensor at present was limited to identification and classification of different genera or species of bacteria, and data from the hyperspectral scattering technique was too huge which seriously affected the speed of data collection. Therefore, there is a desperate need for a rapid, convenient and nondestructive approach for the evaluation of meat freshness.

The main objective of this study was to develop a light scattering system for nondestructively sensing meat's freshness. This system, as an efficient, noninvasive, reagent-less and user-friendly bio-sensing instrument, can be used for rapidly classifying different spoilage degrees of meat. Specific procedures were outlined as follows: (1) a light scattering system was developed to collect scattering images of meat; (2) the region of interest (ROI) was extracted from original scattering images, and then the characteristic variables were extracted from the ROI images; and (3) AdaBoost–OLDA algorithm was applied for modeling, and it was compared with the commonly used classification algorithms.

2. Materials and methods

2.1. Light scattering system

The light scattering system was developed and used for image acquisition of pork meat. Fig. 1 presents the sketch of this system, which was mainly comprised of three parts: (1) a 1 mW power visible laser of 650 nm (We attempted some other lasers (375 nm, 785 nm and 980 nm) in our preliminary test, but we did not obtain the desired results in our limited experimental conditions. In regard to this, we adopted the 650 nm (1 mW) laser instead of other lasers in this work, which finally made significant progress.); (2) a camera with spatial resolution of 640 × 480 pixels, ranging from 400 nm to 1100 nm; and (3) a computer. All samples were placed on the same petri dish and then collected with the light scattering system. The distance from the visible laser to the petri dish, and the distance from the camera to the petri dish, were kept constant during the whole experiment, and determined according to the individual experimental conditions. In this work, the distance of the former was 5 mm, and the distance of the latter was 285 mm. A collimated beam of light generated by visible laser was 5 mm in diameter, and directed through the center of meat sample, which was finally collected as scattering images by camera.

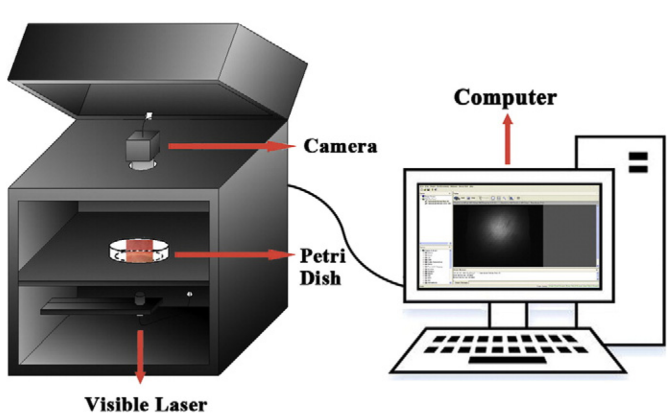

Fig. 1. The sketch of the laser scattering imaging system.

2.2. Sample preparation

Fresh pork filet was purchased from a local supermarket and transported to the laboratory under refrigeration in 30 min. Then it was chopped into pieces of 5 cm × 4 cm × 1 cm (length × width × thickness) uniformly to minimize the influence from varying experiment conditions, and each piece as a sample was placed in a petri dish and stored under 4 °C refrigeration.

2.3. Preliminary test

During pork storage, the nutrition components (carbohydrate, fat, protein, etc.) gradually decompose, producing some small toxic molecular components (organic acids, fatty acids, ammonia, etc.) and bacteria. Total volatile basic nitrogen (TVB-N) in pork meat mainly contains ammonia, trimethylamine and dimethylamine, and the content of TVB-N increases with spoilage caused by either bacterial or enzymatic degradation. Therefore, TVB-N and total viable count (TVC) contents are the two main important quality indices in pork meat.

In this study, 30 pork samples of the 1st day, the 3rd day and the 5th day, were used for determination of TVB-N and TVC contents with conventional methods, semi-micro-Kjeldahl methods for TVB-N content according to China National Standard GB/T 5009.44 (2003), and plate count method for TVC content referred to China National Standard GB/T 4789.2 (2010).

2.4. Imaging acquisition and processing

30 pork samples were stored under 4 °C refrigeration for five days, and images were collected on the 1st day (fresh meat), 3rd day (secondary fresh meat) and 5th day (stale meat) with a light scattering system, totally containing 90 scattering images. Owing to the circular light beam emitted by the laser, the region with useful information was the center circle of meat, and we got the center circle of the acquired images. To ensure that the irrelevant information will not interfere with the analysis, a circular ROI with a radius of 140 pixels was extracted from each scattering image.

2.5. Characteristic variable extraction

Characteristic variables represent scalar properties of the objects, which play an important role in character recognition. The light beam from the visible laser is forced to deviate from its original straight trajectory and spread in all directions while penetrating through meat, thus the light path varied with respect to different spoilage degrees. Therefore, 14 concentric circles of each ROI were extracted every 10 pixels, and then the mean and standard deviation of each circle were extracted as variables, leading to 28 variables. However, this is not sufficient for capturing enough information of pork meat because meat spoilage is the variation in its solid and fluid components, which is structurally and rheologically a complex process. Therefore, gray level co-occurrence matrix (GLCM) was performed for extracting image texture information (Pu, Sun, Ma, & Cheng, 2015). Each element (i, j) in GLCM represents the probability that two pixels with the gray level i and j co-occur in the image separated by a distance along a given direction (0°, 45°, 90°, and 135°). In this study, four textural features including contrast, correlation, energy, and homogeneity were extracted by GLCM texture analysis. Contrast is used to express the local variations presented in the image. Correlation is a measurement of image linearity among pixels. Energy measures the textural uniformity of the image, which is the sum of squared elements in the GLCM. Finally, homogeneity usually measures the closeness of the distribution of elements in the GLCM to its diagonal. Detailed description of these four features can be referred to the listed references (ElMasry, Wang, ElSayed, & Ngadi, 2007; Mohanaiah, Sathyanarayana, & GuruKumar, 2013). Parameters mentioned above were calculated at one distance ($D = 1$) for each