Journal of Food Engineering 149 (2015) 97–104

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Potential of visible/near-infrared hyperspectral imaging for rapid detection of freshness in unfrozen and frozen prawns

Qiong Dai [a], Jun-Hu Cheng [a], Da-Wen Sun [a,b,*], Hongbin Pu [a], Xin-An Zeng [a], Zhenjie Xiong [a]

[a] College of Light Industry and Food Sciences, South China University of Technology, Guangzhou 510641, China
[b] Food Refrigeration and Computerized Food Technology, Agriculture and Food Science Centre, University College Dublin, National University of Ireland, Belfield, Dublin 4, Ireland

ARTICLE INFO

Article history:
Received 28 January 2014
Received in revised form 10 September 2014
Accepted 1 October 2014
Available online 12 October 2014

Keywords:
Prawn
Freshness
Hyperspectral imaging
Successive projections algorithm
Least-squares support vector machines
Adaptive boosting
Artificial neutral network

ABSTRACT

The potential of visible and near infrared (400–1000 nm) hyperspectral imaging as a rapid and non-invasive method was investigated to differentiate freshness of prawns. In both unfrozen and frozen groups (a total of 280 prawns), two different freshness levels were used for classification, respectively. Mean spectral data from the full surface of prawns were extracted automatically as the hyperspectral cubes. Both the first and second derivative spectra were performed for waveform analysis. Successive projections algorithm (SPA) was conducted to select the individual feature wavelengths for classification. Least squares-support vector machine (LS-SVM), adaptive boosting (AdaBoost) algorithm and back-propagation neutral networks (BP-NN) were carried out for classification using the derivative spectrums based on both full wavelengths and selected feature wavelengths. The results demonstrated that SPA–LS-SVM achieved satisfactory average correct classification rate of 98.33% and 95% for prediction samples in unfrozen and frozen groups, respectively. Visualization map of classification of eight prawns (two groups) was also presented. The overall results revealed that hyperspectral imaging technique is promising for freshness classification of prawns rapidly and non-invasively.

1. Introduction

Prawn is a commercially important aquatic product as well as the most favored seafood in the world. Prawn is also a highly perishable product, and therefore common techniques used in the agri-food industry such as drying (Sun, 1999; Sun and Byrne, 1998; Delgado and Sun, 2002; Sun and Woods, 1997), cooling (Wang and Sun, 2001), freezing (Delgado et al., 2009) and edible coating (Xu et al., 2001) can be used to preserve its quality. The general hypothesis proposes that the degradation of prawns is due to biochemical reactions and microbial spoilage (Pornrat et al., 2007; Rzepka et al., 2013), in which the main components of prawns such as protein, carbohydrates, and fat will be decomposed into low molecular weight compounds like trimethylamine, aldehydes, ketones and esters (Kong and Ma, 2003), resulting in the mushiness, off-flavor as well as sensory product rejects. Given the nature of easy death and high perishability, peeled and frozen prawns have occupied most of the market share. However, adulterations of soaked, dead or even deteriorated prawns into unfrozen and frozen prawn products have been reported in many incidents (Curtotti et al., 2011). The soaking process might aggravate the prawn degradation and spoilage by accelerating the activity of the enzyme and microbial contamination in the water. Currently, due to the similar exterior appearance of prawns after peeling and freezing, it is not easy to distinguish the less freshness (soaked, and/or dead) prawns from the fresh ones by naked eyes. In order to provide high-quality products to the market and to improve consumer's confidence in commodities, the rapid and successful detection of freshness in unfrozen and frozen prawns is a necessary task.

Among the traditional methods for freshness identification including sensory (Alimelli et al., 2007), chemical (Bindu et al., 2013) or microbiological methods (Özogul et al., 2005), the total volatile basic nitrogen (TVB-N), as an important and effective reference index in chemical method, is frequently used to evaluate prawn freshness. Nevertheless, these valid and useful methods are not suitable for fast detection of freshness due to the fact that they are commonly laborious, time-consuming and unable to evaluate a large number of samples. As an alternative to these conventional analytical methods, visible and near infrared spectroscopy has been extensively studied and implemented for monitoring quality attributes in foods (Ignat et al., 2014; Ye et al., 2014;

* Corresponding author at: Food Refrigeration and Computerized Food Technology, Agriculture and Food Science Centre, University College Dublin, National University of Ireland, Belfield, Dublin 4, Ireland. Tel.: +353 1 7167342; fax: +353 1 7167493.
E-mail address: dawen.sun@ucd.ie (D.-W. Sun).
URLs: http://www.ucd.ie/refrig, http://www.ucd.ie/sun (D.-W. Sun).

http://dx.doi.org/10.1016/j.jfoodeng.2014.10.001
0260-8774/

Mendoza et al., 2014; Vasconcelos et al., 2014; Vongsvivut et al., 2014). As the spectral properties would vary significantly along with the same prawns, the lack of spatial information became one of the biggest limitations of spectroscopy technique in the on-line application.

Recently, as a rapid and non-destructive detecting technique (Kamruzzaman et al., 2011, 2012; ElMasry et al., 2011b, 2012), hyperspectral imaging (HSI) has received increasing applications for quality and freshness assessment in aquatic products, such as moisture determination of salted coalfish (Wold et al., 2006), assessment of fat and water content distribution in Atlantic halibut, catfish, cod, mackerel, herring and saithe (ElMasry and Wold, 2008), prediction and visualization of pH value (He et al., 2012), texture (Wu et al., 2012a) and color distribution (Wu and Sun, 2013; Liu et al., 2014a) in salmon, detection of parasites in cod (Wold et al., 2001; Sivertsen et al., 2011, 2012), determination of water capacity (Wu et al., 2012b) and identification of gelatin adulteration (Wu et al., 2013) in prawns. By integrating the main advantages of spectroscopy and imaging or computer vision (Valous et al., 2009; Costa et al., 2011; Jackman et al., 2008; Sun, 2004) into one system, hyperspectral imaging can generate a spatial map of spectral variation for samples, resulting in the capability of quantitative measurement for both inherent and extrinsic properties of the specimen as well as their spatial distribution simultaneously (ElMasry et al., 2012; Lorente et al., 2013; Zhu et al., 2013). In this respect, both the chemical and physical changes during food degradation can be detected by HSI. Several researches have investigated the potential of using HSI to determine food freshness (Pu et al., 2014). Sone et al. (2012) used HSI to demonstrate the effects of different packaging on two freshness index (total bacterial count and lipid oxidation) of fish fillets. While Zhu et al. (2012) found that frozen fish can be differentiated according to the freezing speed by visible and near infrared HSI. However, to our best knowledge, no reports of using HSI to rapidly detect freshness in both unfrozen and frozen prawns have been found.

This work investigated the feasibility of visible/near-infrared HSI combined with least squares-support vector machine (LS-SVM) classifiers, adaptive boosting (AdaBoost) and back-propagation neutral network (BP-NN) algorithms to differentiate soaked (less freshness) prawns from fresh prawns in both unfrozen and frozen groups. This study was focused on (1) detecting the spectral variations of four sample groups corresponding to different freshness levels, (2) extracting the hyperspectral cubes from interest regions of prawns automatically, (3) selecting the most informative wavelengths for classification, (4) comparing the prediction abilities of LS-SVM models, AdaBoost and ANN models based on both first and second derivative spectra, and (5) developing an image processing algorithm for visualizing classification.

2. Material and methods

2.1. Sample preparation

Two hundred and eighty live prawns (*Metapenaeus ensis*) each approximately weighting 8–10 g were purchased from a local supermarket in Guangzhou, China. Then the prawns were transported to the laboratories of South China University of Technology alive. In order to extend the freshness level of prawns, four groups of prawns with different processing were included in this study, namely unfrozen–fresh, unfrozen–soaked, frozen–fresh and frozen–soaked groups. 140 prawns was treated with crashed ice to a sudden death, and soaked into 10 L of sea water (25 °C) for two hours (in the pre-experiment, five soaking times (0 h, 1 h, 2 h, 3 h, 4 h) were considered and the freshness levels of prawns were not changed until 2 h of soaking process), while the other 140 prawns was treated to death with the same method without soaking process. Following peeling, 70 soaked prawns and 70 fresh prawns were packaged with plastic bags and stored at a constant temperature of −18 °C for two months (freezing without glaze was preferable for storage of prawns for no more than 2 months (Gonçalves and Junior, 2009) and a linear-increase in TVB-N levels was not found until 2 months of frozen storage (Ahmad and Jeenanunta, 2014), namely 70 for frozen–fresh group and 70 for frozen–soaked group. For comparison, the remaining prawns without freezing were used as unfrozen samples, namely 70 for unfrozen–fresh group and 70 for unfrozen–soaked group. All prawns were allowed to equilibrate to room temperature (25 °C) and wiped with paper towel before scanned by a hyperspectral imaging system. For both frozen and unfrozen groups, eighty samples consisting of 40 fresh and 40 soaked prawns were randomly selected for the calibration set, and the remaining 60 samples of 30 fresh and 30 soaked prawns formed the prediction set (namely, about 60% for calibration, 40% for prediction). The key steps of the experimental procedure are illustrated in Fig. 1.

2.2. Hyperspectral imaging system and data acquisition

In this study, a line-scanning hyperspectral imaging system in reflectance mode was employed to capture the hyperspectral images for each prawn in the wavelength range of 300–1100 nm. The main components of the system included a spectrograph (Imspector V10E, Spectral Imaging Ltd., Oulu, Finland), a 12-bit CCD camera (DL-604 M, Andor, Ireland), two 500 W halogen lamps (3900-ER, Illumination Technologies Inc., New York, USA), a conveying stage operated by a stepper motor (ST-1212-300, Isuzu Optics Corp., Taiwan, China), and a computer supported with spectracube data acquisition software (Spectral Image software; Isuzu Optics Corp., Taiwan, China). The schematic diagram of the main components in the hyperspectral imaging system is illustrated in Fig. 2. After wiping off the surface water with paper towels, the prawns were then placed on the translation platform and moved to the field of view of the camera at a constant speed of 1.5 mm/s. Thus, a total of 280 hyperspectral images were obtained.

2.3. Determination of TVB-N

TVB-N value was determined by the modified method of stream distillation (Cai et al., 2011). Three grams of prawn muscle was minced and then mixed with 27 ml of perchloric acid (0.6 M) and centrifuged at 10,000 rpm for 5 min, and all samples were then cooled to 4 °C. After adding 30 ml of 30% sodium hydroxide, the filtrate was distilled for 5 min in an 8100 Kjeltec Distillation Unit (FOSS Tecator, Höganäs, Sweden) with 30 ml distilled water. Then the distillate was collected by a conical flask, in which 50 ml of boric acid (40 g/L) and a mixed indicator was added. The mixed indicator was created from dissolution of 0.1 g of bromcresol green and 0.1 g of methyl red to 100 ml of 95% ethanol. Afterward, 0.01 M of hydrochloric acid solution was used to titrate the obtained boric acid solution, finally TVB-N content was calculated according to the consumption of hydrochloric acid and expressed as mg N/100 g prawn muscle. Each analysis was repeated in duplicate.

2.4. Image pre-processing

2.4.1. Correction of hyperspectral images

Since the obtained original spectral dataset was the signal intensity of detector, the original hyperspectral images might be affected by the sensitivity of detector and illumination intensity. In order to minimize the differences and deviations among samples caused by environment of instrument, correction of