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# Data fusion and hyperspectral imaging in tandem with least squares-support vector machine for prediction of sensory quality index scores of fish fillet

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ABSTRACT

The study of visible and near-infrared hyperspectral imaging (400–1000 nm) in tandem with data fusion technique was conducted to predict sensory quality index scores (QIS) of grass carp fish fillet for the first time. Five characteristic wavelength variables were selected by successive projections algorithm (SPA) and 13 textural feature variables were also extracted by grey-level gradient cooccurrence matrix (GLGCM) method. Least squares-support vector machine (LS-SVM) was used to build calibration models for predicting QIS estimated by traditional quality index method (QIM) based on full spectra, optimal spectra, image texture parameters and their combined data. The LS-SVM model established by data fusion of optimal spectra and texture data showed the best prediction performance with residual predictive deviation (RPD) of 4.23, coefficient of determination ($R_P^2$) of 0.944 and root mean square error in prediction (RMSEP) of 0.703. Image processing algorithm was then developed to transfer the best LS-SVM model to each pixel for visualizing the spatial distribution of QIS. The results showed that integration of hyperspectral imaging and data fusion coupled with LS-SVM analysis provides a successful quantitative ability for predicting and visualizing the spatial distribution of QIS in grass carp fish muscle.


## 1. Introduction

Fish and fishery products are highly perishable, and common preservation methods such as drying (Sun and Byrne, 1998; Sun and Woods, 1997; Delgado and Sun, 2002a, b), refrigeration (Sun, 1997a, 1997b; Sun, Eames & Aphornratana, 1996; McDonald and Sun, 2001; McDonald, Sun & Kenny, 2001; Kiani and Sun, 2011) and edible coating (Xu, Chen & Sun, 2001) could be used for possible quality maintenance. There are many quality attributes for fish and fishery products, among them freshness is one of the most important ones. Therefore, determination of fish freshness is obviously essential for food quality and safety control. Currently, some methods and techniques developed to measure and evaluate fish freshness are mainly related to sensory evaluation, examining physical properties (colour and texture), microbial methods, measuring volatile compounds and lipid oxidation, determining changes in muscle proteins, and ATP breakdown products in fish (Cheng, Sun, Han, & Zeng, 2014; Cheng, Sun, Zeng, & Liu, 2013; Cheng & Sun, 2015). Among them, as an important evaluation method, sensory evaluation offers the most satisfactory means of assessing the freshness quality of fish and is commonly used in the fish sector and inspection services to provide the best valid consumer acceptability (Barbosa & Vaz-Pires, 2004). As seafood spoils, it goes through a sequence of changes that are detectable by the human senses. Sensory evaluation is defined as the scientific discipline used to evoke, measure, analyse and interpret reactions to characteristics of food as perceived through the senses of sight, smell, taste, touch and hearing (Macagnano et al., 2005).

Quality index method (QIM) as a standardised sensory assessment method is one of the most wholesome and straightforward ways of describing fish freshness (Nilsen & Esaiassen, 2005). In the QIM scheme, the variations of fish quality attributes with storage time mainly related to the appearance, colour, texture, eyes, gills, and abdomen are described and quantitatively analysed by the

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trained panelists. According to the descriptions, quality index score (QIS) is assigned for each quality attribute in a numeric scale using a demerit score system, ranging from 0 to 3. Score 0 normally means the fish very fresh, with scores increasing with storage time (Sveinsdottir, Martinsdottir, Hyldig, Jørgensen, & Kristbergsson, 2002). The demerit scores obtained from all the quality attributes are summarized by the quality index, which increases linearly with storage time in ice. Therefore, QIM has been widely used to evaluate the fish freshness and to predict the remaining shelf life of fish (Nilsen & Esaiassen, 2005).

However, QIM is regularly considered to be subjective, direct contact, time-consuming, not always available along the different steps of the fishery chain and not always practical for large-scale commercial purposes (Nilsen & Esaiassen, 2005). Consequently, in order to satisfy the need for quality measurements in the fish industry, rapid and non-contact instrumental methods and techniques are urgently needed.

As an effective and promising imaging technique, hyperspectral imaging (HSI) shows its great superiority and has recently emerged for rapid and non-destructive quality and safety analysis and control of fish and other seafoods (Cheng & Sun, 2014; Mathiassen, Misimi, Bondø, Veliyulin, & Østvik, 2011; Menesatti, Costa, & Aguzzi, 2010; Zhu, Zhang, Shao, He & Ngadi, 2014). HSI integrates digital imaging technique or computer vision (Sun & Brosnan, 2003; Valous, Mendoza, Sun & Allen, 2009; Jackman, Sun, Du & Allen, 2008; Sun, 2004; Jackman, Sun, Du & Allen, 2009; Wang & Sun, 2002) and spectroscopy into one system to acquire both spatial and spectral information simultaneously from the tested object (Lorente et al., 2012; Sun, 2010). In the HSI system, hundreds of hyperspectral images are captured over a broad spectral range at contiguous and narrow intervals, creating a three-dimensional structure of multivariate data called hypercube (Gowen, O'Donnell, Cullen, Downey, & Frias, 2007). When the hyperspectral data are appropriately processed, it is possible to automatically recognize the position of features displaying specific spectral signatures and to map the gradient and spatial distribution of specific attributes.

This innovative and gifted technique has been successfully developed for food quality analysis (Kamruzzaman, ElMasry, Sun & Allen, 2011; ElMasry, Sun & Allen, 2012; ElMasry, Sun & Allen, 2011; Kamruzzaman, ElMasry, Sun & Allen, 2012; Barbin, ElMasry & SunAllen, 2012; ElMasry, Iqbal, Sun & Allen, 2011; Wu, Sun & He, 2012). For fish freshness evaluation (Khojastehnazhand et al., 2014), it is mainly based on prediction of textural firmness (Cheng, Qu, Sun, & Zeng, 2014), determination of lipid oxidation (Cheng, Sun, Pu, Wang, & Chen, 2014), measurement of colour features (Cheng, Sun, Pu, & Zeng, 2014) and detection of protein degradation (Cheng, Sun, Zeng, & Pu, 2014).

However, to the best of our knowledge, no research endeavours are yet conducted to predict sensory quality index scores (QIS) for evaluation of fish freshness using hyperspectral imaging. Therefore, it is useful to develop this technology for predicting sensory scores in fish fillets in order to replace the costly trained panelists.

The objective of the current study was to examine the feasibility of using visible and near-infrared HSI as a rapid and non-contact method to predict QIS of grass carp (*Ctenopharyngodon idella*) fish fillet. Specific objectives were to (1) develop a visible and near-infrared HSI system in the spectral range of 400–1000 nm, (2) construct least squares-support vector machine (LS-SVM) calibration models to quantitatively correlate syncretic information from spectral and image texture and QIS data measured by traditional trained assessors, (3) select the sensory-related optimal wavelengths by successive projections algorithm (SPA) for predicting QIS, and (4) visualize the QIS distribution map at different storage time.

## 2. Material and methods

### 2.1. Fish sample preparation

A total of twenty fresh grass carp fish from the same batch each weighting approximately 1.5 kg were purchased from a local aquatic products market in Guangzhou, China, and immediately transported to the laboratory alive in water within 15 min. Upon arrival, the fish were stunned by a sharp blow to the head with a wooden stick and then gill cutting. The internal organs were removed at the same time with bloodletting from the fish belly location. Then they were instantly beheaded, filleted, skinned, and washed with cold water. Forty fish fillets with similar size were obtained. In order to acquire more fish samples, the fresh fillets were directly subsampled into a rectangular shape with similar size of 4.0 cm × 3.0 cm × 1.0 cm (length × width × thickness). Consequently, a total of 135 fresh fish subsamples were obtained. Thereafter, all the subsamples as the fresh and first group (G1) were assessed by the trained panel consisting 10 panelists using QIM. After that, the assessed subsamples were immediately labelled and packaged into the sealed plastic bags and randomly divided into the other three groups (G2, G3 and G4) that were subjected to cold storage at 4 ± 1 °C for 2, 4, 6 days. Among the 270 subsamples from four groups, two thirds of the samples ($N = 180$) were randomly selected and used to build the calibration and cross-validation set and the remaining one third samples ($N = 90$) were utilised to construct the prediction set. Table 1 shows the grouping conditions of calibration and prediction set.

### 2.2. QIS measurement

The QIS measurement and the sensory evaluation of each attribute of fish fillet using traditional QIM was conducted according to Martinsdóttir, Sveinsdottir, Luten, Schelvis-Smit, and Hyldig (2001) with some modifications. Changes were made in the setup of the scheme for fish fillet and selection of words to describe the sensory parameters including appearance, odour, colour, and texture in the scheme, mainly to make each description more precise and to facilitate the QIM assessment. In this study, ten trained assessors with several years of experience in evaluating fish freshness from the Food Safety Control Laboratory of South China University of Technology participated in the sensory evaluation with QIM. All observations of the grass carp fish subsamples were conducted under standardized conditions, with as little disturbance as possible, at room temperature, and under white fluorescent light. Every panelist scored three fish subsamples and the means of quality scores were used in further data analysis.

### 2.3. Hyperspectral image analysis

#### 2.3.1. Hyperspectral image acquisition and calibration

A reflectance hyperspectral imaging system in the wavelength range of 400–1000 nm was employed in this study. This system typically consisted of four main parts: a line-scanning imaging spectrograph (ImspectorV10E, Spectral Imaging Ltd., Oulu, Finland)

**Table 1**
The number distribution of calibration and prediction set.

| Group | Total number | Calibration set | Prediction set |
|---|---|---|---|
| | 270 | 180 | 90 |
| G1 (0 d) | 135 | 90 | 45 |
| G2 (2 d) | 45 | 25 | 20 |
| G3 (4 d) | 45 | 30 | 15 |
| G4 (6 d) | 45 | 35 | 10 |