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Review

Selection of feature wavelengths for developing multispectral imaging systems for quality, safety and authenticity of muscle foods-a review

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There is a great interest in developing optical techniques that have the capability of predicting quality attributes, safety parameters and authenticity in real-time assessment. Recently, hyperspectral imaging technique has been widely used for rapid and non-destructive inspection of various food products. Although the technique is currently in an early development stage, its potential is promising. Due to the extensive time needed for the processing of the large volumes of data, hyperspectral imaging technique cannot be directly implemented in an online system. However, selecting some feature wavelengths from hyperspectral images can be useful to develop a multispectral imaging system, which can meet the speed requirement of industrial production. Indeed, the success of multispectral imaging heavily depends on the effectiveness of hyperspectral imaging (HSI) for providing the feature wavelengths. If the high dimensionality of hyperspectral data can be reduced properly in order to design/form a low-cost multispectral imaging sensor based on some selected feature wavelengths for certain applications, the technique would certainly be incomparable for process monitoring and real-time inspection. This review first introduces the fundamental steps for selecting feature wavelengths from hyperspectral data and then describes the feature wavelengths derived from hyperspectral imaging applications to make a more effective and efficient multispectral real-time imaging system. It is anticipated that this review can act as a basis for researchers and industry for further development of online multispectral inspection system for quality, safety and authenticity of muscles food.

Introduction

Muscle foods (i.e. meat from several sources: beef, lamb, pork, chicken, ham) are the most important food products from the perspective of human diet and economic activity. In the meantime, muscle foods are highly perishable, and techniques such as refrigeration (Sun, 1997; Sun & Eames, 1996; McDonald, Sun, & Kenny, 2001; Wang & Sun, 2004; Kiani & Sun, 2011; Zheng & Sun, 2004) and drying (Cui, Sun, Chen, & Sun, 2008; Delgado & Sun, 2002) could be employed to maintain their quality and safety. On the other hand, determination of quality and safety characteristics of raw and processed muscle foods is essential for the meat industry because consumers are constantly demanding superior quality products (Gowen, O'Donnell, Cullen, Downey, & Frias, 2007). Indeed, high quality is a key factor

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for the modern meat industry in today's hypercompetitive marketplace. On the other side, consumers are now more concerned about the meat that they eat, and thus pay more attention in terms of quality, safety, authenticity and animal welfare and also care for the environment and sustainability. All of these concerns have promoted the meat industry migrating from its invasive testing methods still practised in the meat industry to newer, non-destructive techniques (Xiong, Sun, Zeng, & Xie, 2014).

Recently, hyperspectral imaging (HSI) has emerged as a powerful, non-destructive, and non-contact tool for food quality and safety inspection. Hyperspectral imaging, also referred to as imaging spectroscopy, spectroscopic imaging or chemical imaging (ElMasry, Kamruzzaman, Sun, & Allen, 2012; ElMasry, Iqbal, Sun, & Allen, 2011; Barbin, ElMasry, Sun, & Allen, 2012b; Wu & Sun, 2013; Wu, Sun, & He, 2012; Elmasry, Kamruzzaman, Sun, & Allen, 2012; Barbin, Elmasry, Sun, & Allen, 2012a; Cheng & Sun, 2015), is a relatively new technique that integrates imaging or computer vision (Sun & Brosnan, 2003; Jackman, Sun, Du, & Allen, 2008; Costa *et al.*, 2011; Sun, 2004; Jackman, Sun, Du, & Allen, 2008; Wang & Sun, 2002) and spectroscopic techniques, enabling acquisition of spatial and spectral information simultaneously from an object. This information then forms a three-dimensional data cube, which can be analysed to detect, identify, and quantify imaged objects in more details than traditional imaging or spectroscopic techniques (Lorente *et al.*, 2012). So far, hyperspectral imaging technique has received a considerable attention for the quality and safety assessment in muscle foods. Associated with multivariate analyses, it has been successfully implemented for predicting tenderness, pH, colour (ElMasry, Sun, & Allen, 2012; Naganathan *et al.*, 2008a), water holding capacity (WHC) (ElMasry, Sun, & Allen, 2011; Wu *et al.*, 2013), chemical composition (ElMasry, Sun, & Allen, 2013; Kobayashi, Matsui, Maebuchi, Toyota, & Nakauchi, 2010) and microbial spoilage (Peng *et al.*, 2011) in beef, chemical composition (Barbin, ElMasry, Sun, & Allen, 2013), classification (Barbin, ElMasry, Sun, & Allen, 2012b), prediction of quality and sensory attributes (Barbin, ElMasry, Sun, & Allen, 2012a) and microbial spoilage (Tao & Peng, 2015) in pork, muscles discrimination (Kamruzzaman, ElMasry, Sun, & Allen, 2011), prediction of quality attributes (Kamruzzaman, ElMasry, Sun, & Allen, 2012c), chemical composition (Kamruzzaman, ElMasry, Sun, & Allen, 2012b), authentication and adulterate detection (Kamruzzaman, Sun, ElMasry, & Allen, 2013) in lamb meat, freshness (Grau *et al.*, 2011), contaminants (Feng, ElMasry, Sun, Walsh, & Morcy, 2012; Park, Lawrence, Windham, & Smith, 2004), tumour (Du, Jeong, & Kong, 2007), bacterial spoilage (Feng & Sun, 2013a) and adulterate detection (Xiong, Sun, Pu, Zhu, & Luo, 2015) in chicken, and quality classification of cooked, sliced turkey ham (ElMasry, Iqbal, Sun, Allen, & Ward, 2011; Gou *et al.*, 2013; Iqbal, Sun, & Allen, 2013).

Although this technique has not been sufficiently exploited in detecting muscle food quality and safety, a large and increasing number of studies available indicated that the technique would be promising. However, as hyperspectral data have a large volume, which is difficult to record, store, and process efficiently, the technique cannot be implemented in an online system directly. One way to solve this problem is to decrease the data size to assist in the identification of a few key wavelengths for real-time multispectral imaging implementation (Burger & Gowen, 2011). Key wavelengths may be equally or more efficient than full wavelengths if the selected wavelengths carry most of the spectral information (Dai, Sun, Xiong, Cheng, & Zeng, 2014; Lorente, Blasco, *et al.*, 2013). Once the optimal spectral wavelengths are identified, a simple and effective multispectral system can be engineered for industrial applications (Lorente, Aleixos, Gomez-Sanchis, Cubero & Blasco, 2013).

The hyperspectral imaging system is also too expensive to be acceptable by the food processing industry. Therefore, on one hand, it is necessary to select important information (i.e. wavelengths) to improve the efficiency of data processing. On the other hand, it is also necessary to maintain the performance or accuracy based on the selected information. Extensive reviews have been published on hyperspectral imaging for evaluating food quality and safety (ElMasry, Barbin, Sun, & Allen, 2012; Feng & Sun, 2012; Kamruzzaman, Sun, *et al.*, 2013; Xiong, Xie, Sun, Zeng, & Liu, 2015). These reviews showed that many research endeavours were concerned especially with key wavelengths selection (Dai *et al.*, 2014; Nakariyakul & Casasent, 2009; Prieto, Roehe, Lavin, Batten, & Andres, 2009; Pu, Sun, Ma, Liu, & Kamruzzaman, 2014; Zou, Zhao, Povey, Holmes, & Mao, 2010), but a comprehensive review on selection of feature wavelengths associated with specific characteristics of the quality and safety parameters for particular application is not available. The availability of a large and increasing number of studies with continuous emergence of new wavelength selection techniques in recent years necessitates such a review, which will be highly valuable to develop simple and cost effective multispectral sensors for a particular application. Therefore, after presenting the fundamental steps for selecting feature wavelengths from hyperspectral data, this review summarizes the feature wavelengths identified for developing multispectral imaging for detecting muscle food quality, safety and authenticity. It is hoped that this review will motivate researchers and industry in developing online multispectral imaging system for assessing quality, safety and authenticity of muscle foods.

Multispectral imaging and hyperspectral imaging

The concept of multispectral and hyperspectral imaging is similar, but differs in the number of spectral bands used during image acquisition and data generation. Hyperspectral systems collect images in many contiguous and