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Application of NIR hyperspectral imaging for discrimination of lamb muscles

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ABSTRACT

The potential of near-infrared (NIR) hyperspectral imaging system coupled with multivariate analysis was evaluated for discriminating three types of lamb muscles. Samples from *semitendinosus* (ST), *Longissimus dorsi* (LD) and *Psoas Major* (PM) of Charollais breed were imaged by a pushbroom hyperspectral imaging system with a spectral range of 900–1700 nm. Principal component analysis (PCA) was used for dimensionality reduction, wavelength selection and visualizing hyperspectral data. Six optimal wavelengths (934, 974, 1074, 1141, 1211 and 1308 nm) were selected from the eigenvector plot of PCA and then used for discrimination purpose. The results showed that it was possible to discriminate lamb muscles with overall accuracy of 100% using NIR hyperspectral reflectance spectra. An image processing algorithm was also developed for visualizing classification results in a pixel-wise scale with a high overall accuracy.

1. Introduction

Hyperspectral imaging is an emerging, non-contact, cutting-edge analytical technology that combines conventional digital imaging and spectroscopy in a single system. The system provides images in a three-dimensional (3-D) form called "hypercube" which provides spatial information along with spectral information for each pixel in the image. The hypercube is created when hundreds of single gray scale images are stacked behind each other. Each image in the hypercube contains an enormous amount of information about the analyzed object. If this information is properly analyzed, it can be used to characterize the object more reliably than the existing imaging (Kumar and Mittal, 2009; Pallottino et al., 2010; Quevedo et al., 2010) or spectroscopy techniques (Quevedo and Aguilera, 2010; Liu et al., 2010; Klaypradit et al., 2010). The combined nature of imaging and spectroscopy in a hyperspectral imaging enabled this system to simultaneously provide physical and chemical characteristics of an object as well as their spatial distributions (ElMasry et al., 2008; Qiao et al., 2007a; Menesatti et al., 2009).

Discrimination, classification and defects detection is one of the key quality control stages in the food industry. Hyperspectral imaging has a great potential to quantify and control these parameters with high precision. In fruits and vegetables, the technique has been successfully applied in detection of contaminants, bruises and chilling injury in apples (Mehl et al., 2002, 2004; ElMasry et al., 2008, 2009; Xing and De Baerdemaeker, 2005) as well as estimation of quality parameters in strawberry and cucumbers (Nagata et al., 2006; Liu et al., 2005). Moreover, hyperspectral imaging found its way for potential applications in meat products such as fecal and tumour detection in chicken carcass (Park et al., 2007; Nakariyakul and Casasent, 2008; Kong et al., 2004), pork quality classification (Qiao et al., 2007a,b,c), tenderness assessment of beef (Naganathan et al., 2008a,b) and fish quality evaluation (ElMasry and Wold, 2008; Sivertsen et al., 2009).

In the meat industry, quality evaluation and control still performed manually, which is tedious, laborious, costly, time consuming and subject to human error and inconsistency. Accordingly, the meat processing industry seeks non-contact, non-destructive, rapid, accurate and efficient analytical methods for fast evaluation of meat and meat products. Therefore, there is a great interest to work on hyperspectral imaging systems for the evaluation of meat quality. However, hyperspectral imaging technology cannot be directly implemented in an online system for quality evaluation because of the extensive time needed for image acquisition and

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subsequent analysis (Mehl et al., 2002). Hyperspectral imaging technology can be a very useful research tool for determining key wavelengths, which later can be implemented in a real-time multispectral imaging system. These optimum wavelengths not only reflect the physical/chemical information, but also maintain the successive discrimination and classification efficiency (Liu et al., 2007).

Lamb meat is an important source of protein, fat and trace elements. Its quality is influenced by several factors including breed, sex, slaughter weight, feed types and level of feeds, age, pre-slaughter stress, processing and post-mortem ageing (Tejeda et al., 2008; Abd El-Aal and Suliman, 2008). Many studies have been carried out in determining lamb characteristics, but no research endeavours have been reported on quality evaluation of lamb meat by hyperspectral imaging. As a first attempt, the potential of near-infrared (NIR) hyperspectral imaging technique was evaluated for the discrimination of lamb muscles. Accurate classification of muscles is critical for pricing, authentication and categorization of meat. As some meats (muscles, grades etc.) are more valuable for the consumer than others, a rapid, reliable and more accurate technique to identify these meats can be useful for the meat industry. Therefore, the specific objectives of the current study were to:

1. Establish a NIR hyperspectral imaging in the spectral region of 900 to 1700 nm as a tool to discriminate lamb muscles;
2. Indentify key wavelengths that can be used for discrimination of lamb muscles; and
3. Develop image processing algorithms for visualization and classification of the tested lamb muscles.

2. Materials and methods

2.1. Sample preparation

Ten animals of pure *Charollais* breed were slaughtered and dressed according to current EU regulations at a pilot scale abattoir (Ashtown Food Research Centre (AFRC), Teagasc, Dublin 15, Ireland). After slaughtering, carcasses were chilled at 4 °C for 24 h and three muscles of *semitendinosus* (ST), *Longissimus dorsi* (LD) and *Psoas Major* (PM) were selected for the experiment. Each Muscle was cut to slices of 1 inch in thickness using a scalpel and cutting machine. Each sample was individually vacuum packed and shipped to the laboratory of Biosystems Engineering, University College Dublin (UCD) in ice boxes and then kept at 2 °C. A total of 105 lamb samples including PM (35), ST (35) and LD (35) were used for the study. The samples were bloomed for 30 min and surface moisture was wiped by paper towels before image acquisition.

2.2. NIR hyperspectral imaging system

A laboratory NIR hyperspectral imaging system (900–1700 nm) as shown in Fig. 1 was assembled to acquire hyperspectral images of the lamb muscles in the reflectance mode. The hyperspectral imaging system consists of a 12-bit CCD camera (XEVA 992, XC 130 XenICs, Belgium), a spectrograph (ImSpector N17E, Specim, Oulu, Finland), a standard C-mount lens, an illumination unit of two 500-W tungsten halogen lamps (Lowel V-light™, NY, USA), a translation stage (MSA15R-N, AMT-Linearways, SuperSlides & Bushes Corp., India) and a computer supported with a data acquisition software (SpectralCube, Spectral Imaging Ltd., Finland). The camera is equipped with a peltier cooling device to cool the CCD detector to −80 °C to improve the dynamic range and the signal-to-noise ratio of the CCD detector. The area CCD array detector of the camera has 320 × 256 (spatial × spectral) pixels and the spectral resolution was 6 nm in spectral range of 910–1700 nm.

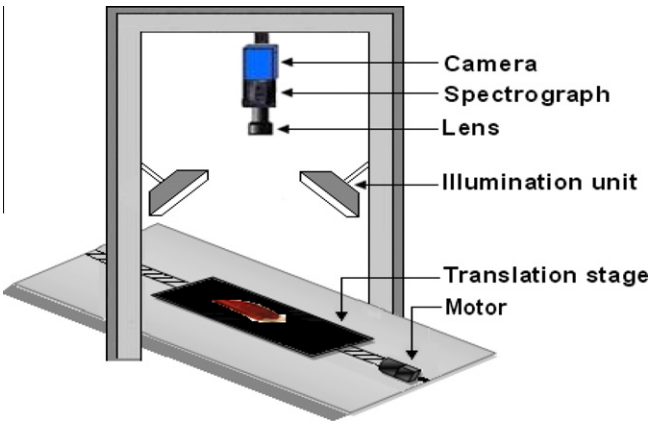

Fig. 1. Schematic representation of the main components of the NIR hyperspectral imaging system.

The system scans the sample line by line and the reflected light was dispersed by the spectrograph and then captured by the area CCD array detector in spatial-spectral ($x \times \lambda$) axes. To construct a full hypercube, the sample was moved at a constant speed of 2.8 cm/s. The movement of the translation stage is synchronized with the camera to obtain spectral images with a spatial resolution of 0.58 mm/pixel. This configuration produces hyperspectral images which were then saved in a band-interleaved-by-line (BIL) format. The main key steps for the whole procedure of image analysis are presented in Fig. 2 and briefly described in the following section.

2.3. Image acquisition and calibration

The image acquisition was carried out at room temperature where lamb sample (PM, ST, and LD) was put on the translation stage and upon entering the field of view, the acquisition of a hyperspectral image of the sample started. Each image was acquired in the spectral range of 910–1700 nm with 3.34 nm intervals between contiguous bands with a total 237 bands. To correct the acquired image (R_0) from the dark current of the camera, a white and dark reference images were captured. The dark reference image (D) of ~0% reflectance was obtained by turning off the light source along with completely closing the lens of the camera with its opaque cap, while the white reference image (W) of ~100% reflectance was acquired for a white Teflon calibration tile. The calibrated image (R) was then calculated using the following equation (ElMasry et al., 2009):

$$R = \frac{R_0 - D}{W - D} \times 100 \quad (1)$$

Image correction, segmentation and extraction of spectral information were carried out using Environment for Visualizing Images (ENVI) software (Research Systems Inc., Boulder, CO, USA).

2.4. Image segmentation

Image segmentation is one of the most important steps in image processing, as subsequent extracted data are highly dependent on the precision of this operation. The main intention of segmentation was to separate only the lamb meat from the background and adjoin fat portion of the sample. All images were processed and analyzed individually and the following procedure was used for the segmentation of each image.

First, the background was removed from the lamb muscle image by subtracting a low-reflectance band from a high-reflectance