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Development of a hybrid image processing algorithm for automatic evaluation of intramuscular fat content in beef *M. longissimus dorsi*

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A B S T R A C T

An automatic method for estimating the content of intramuscular fat (IMF) in beef *M. longissimus dorsi* (LD) was developed using a sequence of image processing algorithm. To extract IMF particles within the LD muscle from structural features of intermuscular fat surrounding the muscle, three steps of image processing algorithm were developed, i.e. bilateral filter for noise removal, kernel fuzzy c-means clustering (KFCM) for segmentation, and vector confidence connected and flood fill for IMF extraction. The technique of bilateral filtering was firstly applied to reduce the noise and enhance the contrast of the beef image. KFCM was then used to segment the filtered beef image into lean, fat, and background. The IMF was finally extracted from the original beef image by using the techniques of vector confidence connected and flood filling. The performance of the algorithm developed was verified by correlation analysis between the IMF characteristics and the percentage of chemically extractable IMF content ($P < 0.05$). Five IMF features are very significantly correlated with the fat content ($P < 0.001$), including count densities of middle (CDMiddle) and large (CDLarge) fat particles, area densities of middle and large fat particles, and total fat area per unit LD area. The highest coefficient is 0.852 for CDLarge.

1. Introduction

Among the visually assessed attributes that determine beef quality, the abundance of intramuscular fat (IMF) is of considerable importance in terms of its perceived effects on eating qualities (Seaman, Hughes, Hinks, Hunter, & Parry, 1994; Hur, Park, & Joo, 2008). Improved acceptability and palatability can be expected for beef steaks with higher content of IMF. Therefore, IMF content might be regarded as an indicator of meat quality (Aass, Gresham, & Klemetsdal, 2006).

One of the proved ways for objective assessment of the IMF level is chemical analysis. Both ether and the chloroform/methanol mixture can be used to extract IMF content. The value obtained by using ether is lower than that by using the chloroform/methanol mixture (Rhee, Smith, & Dutson, 1988), but the result of the latter is influenced by the presence of simultaneously extracted phospholipids and interfering non-lipid components (Pipek, Jeleníková, & Sarnovský, 2004). The ether extraction method (AOAC, 1991) is considered to be an optimal method and commonly used to quantify IMF. For this method, each meat sample should be dried in an oven (100 °C) for at least 24 h followed by petroleum ether extraction in the Soxhlet extractor for another 8 h. This has disadvantages in that chemical analysis is time-consuming, tedious, expensive, destructive, and unable to supply the information of spatial distribution and size of IMF particles. Although the total amount of IMF is important, the distribution and size may also be relevant with meat quality (Ferguson, 2004).

With the advances in image analysis techniques, computer vision has become a technology of great potential for IMF evaluation. Chen, McDonald, and Crouse (1989) pioneered the early works using video image processing techniques to quantify the percentage of IMF on the ribeye surface. Other potential techniques are ultrasound as well as magnetic resonance imaging (MRI). Hassen, Wilson, Amin, Rouse, and Hays (2001) used two types of real-time ultrasound equipment to predict percentage of IMF, while Ballerini et al. (2002) determined fat content from MRI images of beef. However, the automation of this technology for industrial practice still gives problem. To have a practically useful evaluation system for beef IMF, further in-depth research should be conducted to solve the remaining several challenges, e.g. system robustness, real-time capability, sample handling, and standardization (Tan, 2004). The major challenge is to design a system that has sufficient flexibility and adaptability to handle the biological variations in meat products, the core of which is image segmentation.

Since the quality of beef is normally graded by estimating the extent to which *M. longissimus dorsi* (LD) muscle area meets or deviates from a prescribed "expected" value (based on a standard relationship between LD and hot carcass weight) (Steiner et al.,

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Nomenclature

$\mathbf{x}_k$	6-demensional feature vector representing one pixel	u_{ik}	membership value of $\mathbf{x}_k$ for class i
$\mathbf{c}_k$	centroid of kth class	ξ	nearby point
n	number of pixels in an image	$\mathbf{x}$	neighborhood center
J	objective function	l	number of cluster centroids in a image
$\mathbf{c}'_i$	updated new centroid of ith class	$\mathscr{R}$	range domain
σ_s	controlling the extent of the spatial neighborhood used to filter a pixel.	$\mathscr{S}$	spatial domain
σ_r	controlling the discrimination power of an adjacent pixel	$\mathbf{m}_p$	vector mean
$W(\mathbf{x})$	normalization term	w	weighting exponent determining the fuzziness of each membership
D_c	count of all marbling particles per unit LD area	$\mathbf{I}_{in}(\mathbf{x})$	input noisy image
D_{ci}	count of marbling particles in category A_i per unit LD area	$K(\mathbf{x},y)$	kernel function
D_{ai}	marbling area in category A_i per unit LD area	D	Mahalanobis distance
D_a	total marbling area per unit LD area	$\mathbf{I}_{out}(\mathbf{x})$	output denoised image
$\mathbf{p}$	vector representing a pixel	A_1	small marblings
$\mathbf{C}$	cluster centroid matrix	A_2	middle marblings
$\mathbf{C}_p$	covariance matrix	A_3	Large marblings
$\mathbf{U}$	membership matrix	i, j, k	index variable

2003), a good instrument grading system must be able to accurately discern the difference between the LD and other muscles in the cut surface of the ribeye/loineye. As it is difficult to make a distinction between inter- and intra-muscular fat particles of cross-sectional beef rib-eye, Shiranita, Hayashi, Otsubo, Miyajima, and Takiyama (2000) manually specified a rectangle with 340 × 212 pixels inside the outline of beef rib-eye cross-section. In another work, Yoshikawa et al. (2000) made an assumption that the graders settle the vision field of a CCD camera inside the outline of cross-sectional beef rib-eye as large as possible, and its whole area was considered for marbling measurement.

The aim of this study was to develop an algorithm for automatically extracting IMF particles within the LD muscle from structural features of inter-muscular fat surrounding the muscle. The performance of the proposed algorithm was verified by correlation analysis between the IMF characteristics obtained by computer vision and the percentage of chemically extractable IMF content.

2. Materials and methods

2.1. Sample preparation

Fifty heifers were slaughtered at the abattoir of the Meat Industrial Development Unit, Teagasc, Ashtown Food Research Centre, Dublin. The slaughter procedure consisted of stunning using a captive-bolt pistol and exanguination within an average of 60 s. After that, carcasses were dressed, centrally-split into two sides, and then entered the chill room at ≈2 °C for 2 days postmortem. Fifty steaks (5.08 cm thick) were obtained by excision of LD muscle (between 10th and 11th ribs). The obtained steaks were further cut into two parts evenly (2.54 cm thick) for imaging and chemical analysis respectively, and individually vacuum-packed. It should be noted that the cut surface was used for imaging for each steak. Animal breed is the main variable among the steaks analyzed by computer vision and chemical analysis, including Charolais cross, pure Charolais, Aberdeen Angus, and Belgian Blue. Among these breeds, Belgian Blue has much more lean meat and less fat, while Aberdeen Angus has more fat.

2.2. Image acquisition

The image acquisition system used in this study consisted of a Dell Workstation 400 equipped with an IC-RGB frame grabber (Imaging Technology, US), and a 3-CCD Sony XC-003P camera (Sony cooperation, Japan). To minimise colour effects due to the chemical interaction with oxygen, each beef steak was taken out of the vacuum bag and put in a refrigerator for 1 h. The steak image was then captured on a blue background under four fluorescent lamps with plastic light diffusers and a polarizer, and was saved in three-dimensional RGB (red, green, and blue) colour space. For each experiment, the same exposure and focal length were used for all the images, which were in the same size of 720 × 574 (413280 pixels) with 24 bits per pixel, and saved in the image format of TIFF (Tag Image File Format).

2.3. Image analysis

It is a challenging task to develop an image analysis algorithm capable of accurately and automatically extracting the IMF particles from an input image that completely includes the whole region of LD muscle. In this work, a hybrid image processing method was developed, which combined the techniques of bilateral filtering (Tomasi & Manduchi, 1998) for noise removal, kernel fuzzy c-means clustering (KFCM) for segmentation, and vector confidence connected (Yoo et al., 2002) and flood fill (Soille, 2003) for IMF extraction.

2.3.1. Noise removal

Beef images captured by the CCD camera are inevitably subject to various types of noise, such as the reflection of light and the unevenness of exposure to light sources. This noise may degrade the quality of beef images and consequently the captured images cannot provide correct information for subsequent image segmentation, which is based on the difference in the color of pixels. The color heterogeneity induced by noise could lead to nonrobust results. In order to improve the quality of beef images and make the proposed system practical, operations need to be performed to remove or decrease degradations suffered in their acquisitions. As a nonlinear filter that smoothes an image while preserving edges, the bilateral filter originally proposed by Tomasi and Manduchi (1998) was employed as a heuristic tool for noise removal in beef images.

The implementation of bilateral filtering is noniterative, local, and simple where the output denoised image $\mathbf{I}_{out}(\mathbf{x})$ is a weighted average of the input noisy image $\mathbf{I}_{in}(\mathbf{x})$. It combines colors based on