Beef Marbling Image Segmentation Based on Homomorphic Filtering

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Abstract—In order to reduce the influence of uneven illumination and reflect light for beef accurate segmentation, a beef marbling segmentation method based on homomorphic filtering was introduced. Aiming at the beef rib-eye region images in the frequency domain, homomorphic filter was used for enhancing gray, R, G and B 4 chroma images. Then the impact of high frequency /low frequency gain factors on the accuracy of beef marbling segmentation was investigated. Appropriate values of gain factors were determined by the error rate of beef marbling segmentation, and the results of error rate were analyzed comparing to the results without homomorphic filtering. The experimental results show that the error rates of beef marbling segmentation was remarkably reduced with low frequency gain factor of 0.6 and high frequency gain factor of 1.425; Compared with other chroma images, the average error rate (5.38%) of marbling segmentation in G chroma image was lowest; Compared to the result without homomorphic filtering, the average error rate in G chroma image has decreased by 3.73%.

Index Terms—Beef; Marbling; Homomorphic Filter; Image Segmentation

I. INTRODUCTION

Beef color, marbling and surface texture are key factors used by trained expert graders to classify beef quality [1]. Of all factors, the beef marbling score is regarded as the most important indicator [2]. The Ministry of Agriculture of the People's Republic of China has defined four grades of beef marbling and correspondingly published standard marbling score photographs. Referring to the standard photographs, graders determine the abundance of intramuscular fat in rib-eye muscle and then label the marbling score [3]. Since the classification of beef marbling score largely depends on the subjective visual sensory of graders, the estimation on the same beef region may differ. Therefore, developing an objective system of beef marbling grading independent on subjective estimation is imperative in beef industry.

Beef marbling, which is an important evaluation indicator in the existing beef quality classification criteria, is usually determined by the abundance of intramuscular fat in beef rib-eye region. Machine vision and image processing technology are considered as the most effective methods in automatic identification of beef marbling grades [4]. In automatic identification, the first thing is to precisely segment beef marbling. Numerous methods for beef marbling image segmentation have been reported in the past 20 years. For the first time, Ref. [5] segments the image of beef rib-eye section into fat and muscle areas by image processing, and then calculates the total area of fat, and obtains the relationship between fat area and the sensory evaluation results of beef quality. Ref. [3] proposes a beef marbling image segmentation method based on grader's vision thresholds and automatic thresholding to correctly separate the fat flecks from the muscle in the rib-eye region and then compares the proposed segmentation method to prior algorithms. Ref. [6] proposes an algorithm for automatic beef marbling segmentation according to the marbling features and color characteristics, which uses simple thresholding to remove background and then uses clustering and thresholding with contrast enhancement via a customized grayscale to remove marbling. And the algorithm is adapted to different environments of image acquisition. Due to complex and changeable beef marbling, no clear boundary can be discerned between muscle and fat areas. Therefore, marbling can hardly be precisely segmented. The results of Ref. [7] show that fuzzy c-mean (FCM) algorithm functioned well in the segmentation of beef marbling image with high robustness. On this basis, Ref. [8] uses a sequence of image processing algorithm to estimate the content of intramuscular fat in beef longissimus dorsi and then uses a kernel fuzzy c-means clustering (KFCM) method to segment the beef image into lean, fat, and background. Ref. [9] presents a fast modified FCM algorithm for beef marbling segmentation, suggesting that FCM is highly effective. Ref. [10, 11] introduces a kind of method to segment the area of longissimus dorsi and marbling from rib-eye image by using morphology filter, dilation, erosion and logical operation. Ref. [12] uses computer image processing technologies to segment the lean tissue region from beef rib-eye cross-section image and to extract color features of each image, and then uses BP neural network to predict the color grade of beef lean tissue. Ref. [13, 16] establish a kind of predicting models for beef marbling grading, indicating that beef marbling grades could be determined by using fractal dimension and image processing method. Ref. [14] developed a beef image online acquisition system according to the requirements of beef automatic grading industry. In order to reduce the calculating time of the system, only Cr chroma image are

considered to extract the effective rib-eye region by using image processing methods. Ref. [15] uses machine vision and support vector machine (SVM) to determine color scores of beef fat. And the fat is separated from the rib-eye by using a sequence of image processing algorithms, boundary tracking, thresholding and morphological operation, etc. Then twelve features of fat color are used as inputs to train SVM classifiers. As machine vision technology aims to objectively assess marbling grades, a machine vision system will first collect the entire rib-eye muscle image of a beef sample. Then the sample image can be segmented into exclusively marbling region and rib-eye region images with the image processing algorithm. As a result, marbling features can be computed according to the processed images, which are more prone to objectively and consistently determine beef marbling grading compared with visual sensory. However, in collection of beef rib-eye images, the unfavorable light and acquisition conditions will unavoidably cause problems, such as overall darkness, local shadow, and local reflection, which increase the difficulty in subsequent marbling segmentation and reduce the segmentation precision.

Homomorphic filtering is a special method that is often used to remove multiplicative noise. Illumination and reflectance are not separable, but their approximate locations in the frequency domain may be located. Since illumination and reflectance combine multiplicatively, the components are made additive by taking the logarithm of the image intensity, so that these multiplicative components of the image can be separated linearly in the frequency domain. Illumination variations can be thought of as a multiplicative noise, and can be reduced by filtering in the log domain. To make the illumination of an image more even, the high-frequency components are increased and low-frequency components are decreased, because the high-frequency components are assumed to represent mostly the reflectance in the scene (the amount of light reflected off the object in the scene), whereas the low-frequency components are assumed to represent mostly the illumination in the scene. That is, high-pass filtering is used to suppress low frequencies and amplify high frequencies, in the log-intensity domain. As a result, the uneven illumination of color images can be effectively corrected [17-25]. In this paper, homomorphic filtering is used to correct the non-uniform illumination in the beef rib-eye region, and thereby the effects of filtering gain factors and 4 chroma images on marbling segmentation precision are analyzed. Based on this, a beef marbling segmentation method based on homomorphic filtering with G chroma image was introduced.

This paper proposes an accurate beef marbling segmentation method based on homomorphic filtering theory, and the specific work is as follows:

(a) Homomorphic filtering is a generalized technique for signal and image processing, involving a nonlinear mapping to a different domain in which linear filter techniques are applied, followed by mapping back to the original domain. Homomorphic filter is sometimes used for image enhancement. It simultaneously normalizes the brightness across an image and increases contrast. In order to find out the optimal chroma image to extract beef marbling area accurately, homomorphic filtering in this paper is used respectively to enhance gray, R, G and B 4 chroma images in beef rib-eye region in the frequency domain and then the beef marbling areas are extracted by Otsu method.

(b) Homomorphic filtering is used to correct the illumination and reflection variations of beef rib-eye images, which will affect the beef marbling extraction to some extent. In order to select appropriate high/low gain factor values of homomorphic filter to enhance the contrast ratio in the beef rib-eye region, the impact of high /low frequency gain factors on the accuracy of beef marbling segmentation is investigated. Corresponding to different high/low frequency gain factor values of homomorphic filter, the error rate curves of marbling segmentation in gray, R, G and B chroma images are plotted. Then the minimum error rate curves of the 4 chroma images are plotted and the trends of the minimum error rates corresponding to high/low frequency gain factors are discussed.

(c) In order to achieve the optimal beef marbling segmentation effect, the segmentation error rates with different chroma images are analyzed and compared. The average values of high/low frequency gain factors are selected to segment marbling. Then the error rate results with homomorphic filtering are compared to those without homomorphic filtering.

The rest of paper is organized as follows. The materials and proposed methods are presented in Section 2. Then the impact of homomorphic filter gain factors and different chroma images on the accuracy of beef marbling segmentation is discussed in Section 3. Finally, the conclusions are given in Section 4.

II.   PROPOSED METHOD

Under natural illumination, 10 beef rib-eye images (640×480 pixels) were collected by using a Minolta Z1 digital camera and stored as JPG format in PC. The PC has a Pentium(R) Daul-Core CPU (basic frequency 2.6 GHz), a memory of 2.0 GB, and an operating system of Windows XP. Image processing and data analysis are performed on Matlab software.

Before segmentation, preprocessing is needed to separate the rib-eye region for subsequent marbling segmentation. The separation includes threshold setting, regional growth, and morphological processing (details in Ref. [11]).

Homomorphic filtering is used to correct the uneven illumination in beef images and thus reduce the effects of darkness and reflection on subsequent image processing. This provides a favorable foundation for accurate segmentation of beef marbling. The principle is as follows.

In the illumination-reflection model, image $f(x, y)$ can be expressed as the product of the illumination component $i(x, y)$ and the reflection component $r(x, y)$:

$$f(x, y) = i(x, y) \cdot r(x, y) \tag{1}$$

where $0 < i(x, y) < \infty$, and $0 < r(x, y) < 1$.

First, the logarithm of $f(x, y)$ is obtained:

$$\begin{aligned} z(x, y) &= \ln f(x, y) \\ &= \ln i(x, y) + \ln r(x, y) \end{aligned} \tag{2}$$

By using Fourier transform, then

$$F[z(x, y)] = F[\ln i(x, y)] + F[\ln r(x, y)] \tag{3}$$

or

$$Z(u, v) = I(u, v) + R(u, v) \tag{4}$$

The filter's transfer function $H(u, v)$ is designed as:

$$\begin{aligned} S(u, v) &= H(u, v)Z(u, v) \\ &= H(u, v)I(u, v) + H(u, v)R(u, v) \end{aligned} \tag{5}$$

By using inverse Fourier transform on $S(u, v)$, then:

$$\begin{aligned} s(x, y) &= F^{-1}[S(u, v)] \\ &= F^{-1}[H(u, v)I(u, v)] + F^{-1}[H(u, v)R(u, v)] \end{aligned} \tag{6}$$

Let

$$i'(x, y) = F^{-1}[H(u, v)I(u, v)] \tag{7}$$

and

$$r'(x, y) = F^{-1}[H(u, v)R(u, v)] \tag{8}$$

Then equation (6) can be expressed as:

$$s(x, y) = i'(x, y) + r'(x, y) \tag{9}$$

Finally, because $z(x, y)$ is the logarithm of the original image $f(x, y)$, the inverse operation (exponential) can be used to generate a satisfactory enhanced image, which can be expressed by $g(x, y)$ as:

$$\begin{aligned} g(x, y) &= e^{s(x, y)} \\ &= e^{i'(x, y)} \cdot e^{r'(x, y)} \\ &= i_0(x, y) r_0(x, y) \end{aligned} \tag{10}$$

where

$$i_0(x, y) = e^{i'(x, y)} \tag{11}$$

$$r_0(x, y) = e^{r'(x, y)} \tag{12}$$

are the illumination component and reflection component of the output image respectively.

A Gaussian high-pass filter $H(u, v)$ is selected as the homomorphic filter's function:

$$H(u, v) = (r_H - r_L)[1 - e^{-c(D^2(u, v))/D_0^2}] + r_L \tag{13}$$

where $D_0(u, v)$ is cut-off frequency, $D(u, v)$ is the frequency at point (u, v); c is a constant; $r_H \in (0, \infty)$ is

high frequency gain factor; $r_L \in (0, 1]$ is low frequency gain factor. Appropriate values of high/low gain factors should selected, so as to enhance the contrast ratio of the image in the beef rib-eye region, sharpen the image edges and details, and make marbling segmentation more effectively.

The processed beef rib-eye images undergo gray-scale transformation; then the gray and R, G and B 4 chroma images undergo the above homomorphic filtering. Otsu automatic threshold method is used for dividing the rib-eye region into the target (muscle) and the background (fat). With the optimal threshold, image $g(x, y)$ is binaryzed:

$$g(x, y) = \begin{cases} 0 & (g(x, y) \geq T) \\ 255 & (g(x, y) \leq T) \end{cases} \tag{14}$$

In order to evaluate the effects of beef marbling segmentation, the precision of segmentation should be analyzed. Marbling segmentation error rate Q is defined as the error ratio of pixel counts between the extracted marbling region after processing and the marbling region manually segmented from the original image [14]. The pixel count in the manually segmented marbling region is expressed as $q(x, y)$; the pixel count in the extracted marbling region after processing is expressed as $q'(x, y)$; then the beef marbling extraction error rate is calculated as:

$$Q = \frac{|\sum q'(x, y) - \sum q(x, y)|}{\sum q(x, y)} \times 100\% \tag{15}$$

Manual segmentation is performed on Photoshop. The pixel count in the marbling region is summarized. In order to reduce manual extraction error, each image is repeated 3 times to obtain the average value, which is used as the marbling pixel count by deleting decimal part.

III. RESULTS AND DISCUSSION

A. Beef Marbling Extraction Based on Homomorphic filtering

One image (Fig. 1) is randomly selected from the collected beef images. After preprocessing as described in Section 2, the rib-eye image is obtained (Fig. 2). Then the rib-eye image undergoes gray-scale transformation (Fig. 3) for homomorphic filtering with different frequency gain factors, and the rib-eye image is showed in Fig. 4.

Figure 1.   Original beef sample image

Figure 2.   Beef rib-eye image

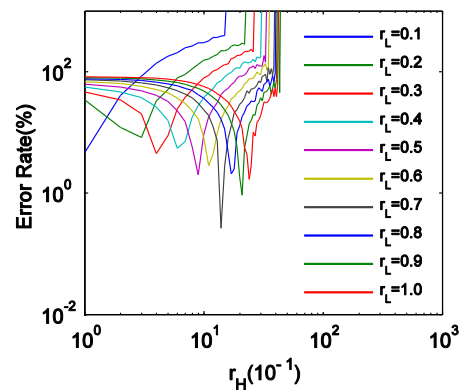
Figure 3.   Rib-eye gray image

As showed in Fig. 2 and Fig. 3, because of light insufficiency, the rib-eye image lacks brightness, so the contrast between marbling and muscle is small and some tiny marbling is unclear. After homomorphic filtering, the brightness is improved (Fig. 4a), especially the edges are sharpened, so the tiny marbling fragments are enhanced. However, when different values of r_L and r_H are used, the filtering effects are different. When a small gain factor is used, the image brightness is too large, while the contrast between marbling and muscle is significantly reduced (Fig. 4b), which is unfavorable for subsequent segmentation. When a large gain factor is used, the high frequency part will be excessively enhanced, so the brightness decreases (Fig. 4c), which is also unfavorable for subsequent segmentation. Therefore, appropriate values of gain factors should be selected to improve beef marbling segmentation precision.

(a) r_L=0.8, r_H=1.2

(b) r_L=0.2, r_H=0.2

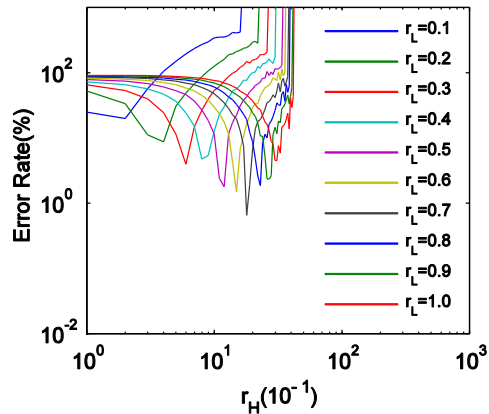(c) r_L=0.9, r_H=1.8

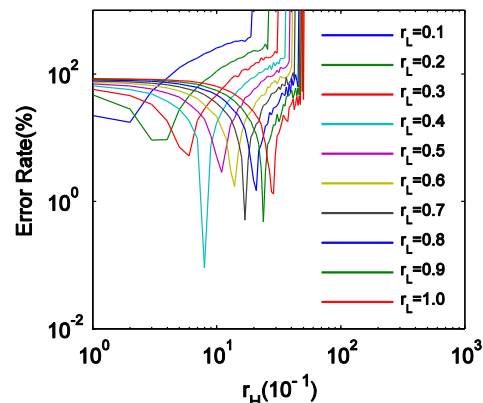Figure 4.   Rib-eye gray image
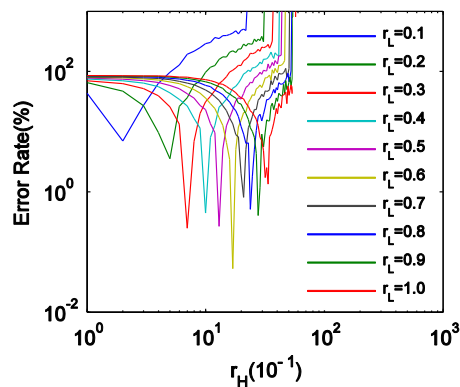
(a)   R chroma image

(b)   G chroma image

(c)   B chroma image

(d)   Gray chroma image

Figure 5.   Rib-eye gray image

B. Selection of Homomorphic Filtering Gain Factors and Their Effects on Beef Marbling Segmentation Precision

Homomorphic filtering is used to correct the illumination and reflection components of rib-eye images, which will affect the beef marbling segmentation to some extent. Appropriate values of homomorphic filtering gain factors r_L and r_H are selected, so as to enhance the contrast ratio in the beef rib-eye region.

One image is selected from the 10 images, then the rib-eye region is segmented as described in Section 2; different values of r_L and r_H are selected to construct different filters. Then the gray, R, G and B 4 chroma images undergo homomorphic filtering separately. Finally, the marbling is extracted as described in Section 2 and the error rates are calculated as described in Section 2. The results are listed in Fig. 5.

Fig. 5 shows that when r_L is constant, the beef marbling extraction error rates in the 4 chroma images all slowly decrease firstly and then sharply increase with the increasing r_H. Each beef marbling segmentation error rate curve corresponding to each value of r_L shows a minimum error rate. For instance, in gray chroma image, when r_L =0.4 and r_H =0.8, the beef marbling error rate is minimized to 0.08%.

Then the minimum error rates of the 4 chroma images under both r_L and r_H are used for obtaining the changing curves (Fig. 6 and Fig. 7).
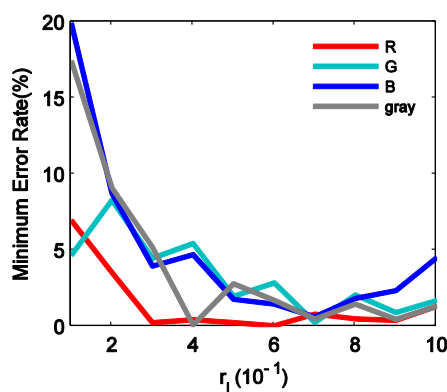

Figure 6.   Effects of low frequency gain factor on minimum error rate in beef marbling segmentation
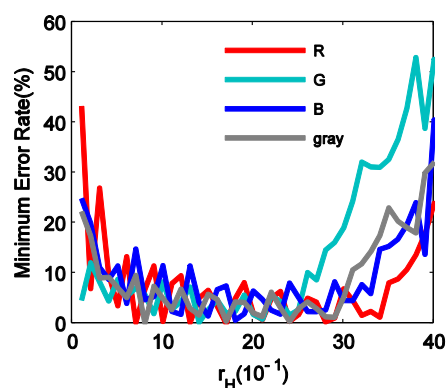

Figure 7.   Effects of high frequency gain factor on minimum error rate in beef marbling segmentation

Fig. 6 shows that with the increase of r_L, the minimum error rate firstly decreases and then increases, and concentrates within r_L =0.4-0.8. Fig. 7 shows that with the increase of r_H, the minimum error rate also firstly decreases and then increases, and concentrates within r_H =0.8-1.8. Specifically, for gray chroma image, the minimum error rate is 0.08% when r_L =0.4 and r_H =0.8; for R chroma image, the minimum error rate is 0.05% when r_L =0.6 and r_H =1.7; for G throma image, the minimum error rate is 0.27% when r_L =0.7 and r_H =1.4; for B chroma image, the minimum error rate is 0.64% when r_L =0.7 and r_H =1.8.

C. Analysis and Comparison of Marbling Segmentation Error Rates Based on Homomorphic Filtering

The above analysis shows that within r_L =0.4-0.8, and r_H =0.8-1.8, the gray, R, G and B chroma images after homomorphic filtering show the minimum error rates, and therefore, r_L and r_H are arithmetically averaged to r_L =0.6 and r_H=1.425. The 10 images are preprocessed as described in Section 2 to segment the beef rib-eye regions; then a homomorphic filter with r_L of 0.6 and r_H of 1.425 is used for filtering the gray, R, G and B 4 chroma image and thereby for segmenting marbling area. Finally equation (15) is used to calculate the error rates of the 4 chroma images for each beef image, and the results are listed in Table 1.

TABLE I.   ERROR RATE IN BEEF MARBLING SEGMENTATION WITH HOMOMORPHIC FILTERING

Image No.	Chroma Image			
	Gray	R	G	B
1	10.97	16.62	6.91	15.59
2	10.24	21.05	0.40	14.41
3	3.38	13.86	7.44	2.97
4	6.56	17.82	4.46	10.91
5	1.41	13.29	10.27	5.99
6	15.02	25.26	4.95	18.97
7	6.85	22.38	5.82	12.57
8	12.77	17.42	9.25	9.86
9	4.45	16.12	1.71	10.36
10	8.48	18.69	2.56	20.03
Mean	8.01	18.25	5.38	12.17

TABLE II.   ERROR RATE IN BEEF MARBLING SEGMENTATION WITHOUT HOMOMORPHIC FILTERING

Image No.	Chroma Image			
	Gray	R	G	B
1	11.71	19.87	8.82	15.29
2	20.53	23.29	7.12	15.13
3	13.30	10.83	5.65	14.27
4	22.47	27.82	14.46	20.91
5	12.39	16.48	12.72	10.63
6	14.11	16.37	9.53	22.12
7	17.41	22.56	6.98	16.94
8	12.99	14.78	14.32	13.57
9	9.67	15.96	6.61	18.59
10	14.82	20.16	4.84	23.79
Mean	14.94	18.81	9.11	17.12

Table 1 shows that after homomorphic filtering, the error rates of all the 4 chroma images are different. The

minimum error rate is from G chroma images, which is 5.38%, significantly lower than gray chroma image (8.01%), R chroma image (18.25%) and B chroma image (12.17%), indicating that G image can be used to obtain the optimal segmentation effect.

Table 2 shows the error rates of beef marbling extraction without homomorphic filtering (only with Otsu method).

Table 2 shows that without homomorphic filtering, the minimum error rate is also from G chroma image (9.11%), significantly lower than the average error rate of gray, R, or B images. However, the error rates without homomorphic filtering are all higher than those with homomorphic filtering. The average error rate in G chroma images is 3.73% higher than that after filtering, indicating that the beef marbling error rate decreases significantly after homomorphic filtering.

IV. CONCLUSIONS

(1) After homomorphic filtering, beef rib-eye images are improved and much tiny marbling is enhanced. Appropriate values of frequency gain factors should be selected, which is favorable for precise segmentation of beef marbling.

(2) High/low frequency gain factors both significantly affect the error rate of beef marbling segmentation. With the increase of either factor, the minimum error rate firstly decreases and then increases. When high frequency gain factor r_H is within 0.8-1.8, and when low frequency gain factor r_L is within 0.4-0.8, the beef marbling error rate could get the minimum value.

(3) r_L =0.6 and r_H =1.425 are selected to build a homomorphic filter to process the beef rib-eye images; the minimum error rate is from G chroma images, which is 5.38%, about 3.73% lower than that without homomorphic filtering. This indicates that with this gain factor, G images after homomorphic filtering can achieve the optimal beef marbling segmentation effect.

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