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AN ON-LINE NON-DESTRUCTIVE BEEF FAT CONTENT DETECTING SYSTEM BASED ON MAXIMUM ENTROPY SEGMENTATION

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Abstract. *Fat content is an important index of basis of beef quality. This paper studied and developed an on-line non-destructive detection system for beef fat content, which includes the overall design of the system scheme, the hardware design and functions, the software functions and detection algorithm. The systematical hardware is composed of image acquisition unit, transmission unit and processing unit. For the software implementation, Otsu algorithm was performed to isolate the beef image background, and R layer in RGB color space was used to isolate accurately at first. Then, a maximum entropy segmentation method was presented to estimate the fat content compared with other 3 methods. And the results were analyzed to contrast with the results by Soxhlet extractor method. The testing of 50 samples has shown that the method is accurate for estimating fat content and the system is a fast and effective on-line detecting system.*
Keywords: Beef, Fat content, On-line detecting system, Maximum entropy

1. **Introduction.** In 2012, beef production total quantity reached 7 million tons in China, which is only inferior in the United States and Brazil in the world. And the quality of beef is paid more attention to by consumers. Fat content is one of the most important standards of measuring beef quality. The higher intramuscular fat (IMF) content means the beef quality is better and shows marbling. The traditional method of detecting fat content is chemical methods, which takes a long time and is destructive. Therefore, research on non-destructive and fast detecting methods is popular in recent years.

In non-destructive detecting methods, there are mainly four methods including ultrasonic method, near-infrared method, NMR image analysis method and computer vision method [1]. In ultrasonic method, fat and salt content of meat can be detected, but the errors of detecting fat content were big [2]. NMR method analyzes NMR images to predict fat content in [3,4], the results are accurate, but the facility is expensive and not convenient to use. In near infrared method, though the detection results are accurate, they are easily influenced by fat meat, which is big and attached to lean meat in [5]. Computer vision method estimates fat content by analyzing the pictures, which is fast, much cheaper and convenient [6]. In [7], a method which judged the optimal threshold between lean and fat by eye muscle image gray histogram is presented, but the accuracy is low. Marbling score and grey space correlation matrix were used to analyze the image features of fat and lean structures in [8], and it can extract the characteristic information and appears accurate by experiments, but has certain limitations in lab conditions. [9] extracts the characteristic of the marbling content and calculates the intramuscular fat content by the multiple linear regression, nonlinear regression and neural network, but it has a large number of requirements and is impractical.

There are a few on-line meat quality detection systems, which are studied and have already made considerable success, but also need to be improved. In [10], an on-line device was developed by NIR and visible spectroscopy. Traits evaluated were pH value, water content and color, but there are relatively small root mean square errors. In [11], tenderness and Escherichia coli of pork meat were detected by line-scanning hyperspectral imaging system with a CCD camera and an imaging spectrograph. It has potential for on-line detection.

In this paper, a non-destructive on-line system for predicting beef content is presented based on machine vision and image processing technology. Section 2 introduces the overall composition and process of the system. Section 3 presents the explanation of software design. This work employs maximum entropy segmentation method to identify beef fat and predict fat content. And the hardware design and function of every unit are presented in Section 4. Section 5 shows the experimental results compared with chemical method, and the discussion. Finally, Section 6 shows the conclusions.

2. The Overview of On-Line System.

2.1. The composition of on-line detecting system. The on-line detecting system for predicting beef fat content needs to construct automatic data acquisition and processing system based on computer vision. It can automatically acquire the beef sample images that placed in production line and process them in real time. This system includes a camera, a transfer device, a control circuit and a computer with video capture card. The schematic diagram is shown in Figure 1.

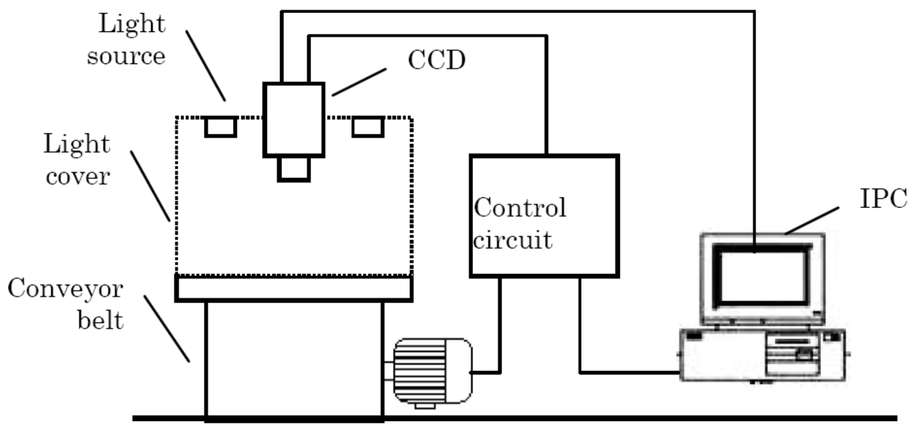

FIGURE 1. The schematic diagram of on-line detecting system

The blueprint of on-line detection system without computer shows in Figure 2, in which Figure 2(a) is the top view of the system, and Figure 2(b) is the main view. In Figure 2(b), 1 is a CCD camera with two LED lights beside it. It connects to the computer. 2 is an opaque cover for preventing the light outside. 3 is a conveyor belt with grid that is used for laying beef. 4 is a stepper motor, which drives the belt to move a grid each time.

2.2. The operational process of detecting system. Firstly, tile the beef sample on the grid of conveyor belt. The stepper motor drives the conveyor belt to move to make the beef sample under the camera. Secondly, the beef images are captured and transmitted to the computer. Thirdly, the computer processes images in real time and analyzes to

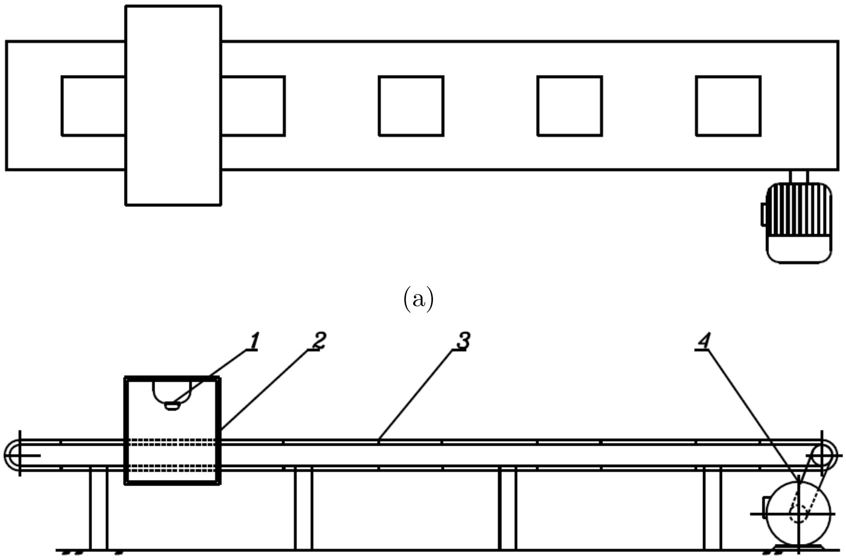

Figure 2. The top view and main view of on-line detecting system

output the detecting results. Then, the computer instructs the control circuit to regulate the motor. Finally, repeat above processes to detect next beef sample.

3. **The Software Design.** In this section, a beef fat content detecting method is presented as the software part.

3.1. **Fat content detecting method based on maximum entropy.** For predicting beef fat content, fat and lean regions of meat must be segmented accurately at first. In image segmentation methods, maximum entropy method has quick speed, simple calculation and good segmentation quality, which has been widely applied [12]. The main idea of maximum entropy segmentation method is [13]: the image pixels are classified by selecting one or more optimal threshold. Generally, the image pixels' value less than the threshold value are supposed to be one category and the pixels' value greater than the threshold is classified as another category. The key problem is how to choose the optimal threshold. The maximum entropy segmentation determines the optimal threshold as follows.

Set the information entropy of image is H_L, information entropy of objective in image is H_o, and information entropy of background is H_b, and then

$$H_L = H_o + H_b \tag{1}$$

Set the image segmentation threshold is (s, t) [14], the probability of background region is P_b, the probability of the target area is P_o, and then the discriminate function of image entropy is defined as

$$\begin{aligned}(s, t) &= H_o + H_b \\ &= \frac{H_o}{P_o} + \lg H_o + \frac{H_L - H_o}{1 - P_o} + \lg(1 - P_o) \\ &= \lg[P_o(1 - P_o)] + \frac{H_o}{P_o} + \frac{H_L - H_o}{1 - P_o}\end{aligned} \tag{2}$$

The optimal threshold vector (s^*, t^*) has to satisfy the following condition

$$(s^*, t^*) = \max(f(s, t)) \tag{3}$$

This paper applied maximum entropy method to segmenting the image, and improved it to separate the fat regions from meat. The main color of lean meat is red, but it is white for fat. Therefore, the R layer in RGB color space appears significantly different between lean and fat. In order to compare the segmentation effects of different methods, this paper also studied the minimal cross-entropy segmentation method, Otsu method and HSV color space segmentation method under the same conditions, analyzing and discussing their segmentation results in experiment.

The fat content of beef is measured by fat percentages, which are obtained by maximum entropy segmentation method and also are calculated by Equation (4)

$$p = \frac{S_{fat}}{S_{total}} \times 100\% \tag{4}$$

where p is the fat percentage. S_{fat} is the fat area measured as pixels. S_{total} is the beef total area.

3.2. **The process and methods of the software.**

- Image pre-processing. This paper selected median filter to smooth noise, which is a nonlinear signal processing technology based on the order statistical theory, and it can effectively suppress the noise.
- Background segmentation. The background of images may influence the results of detecting [15]. In this paper, the background of beef image is segmented by Otsu algorithm, which has the characteristics of simple computation and stable effects.
- Fat segmentation and fat content detection. In this step, fat and lean meat is separated by maximum entropy method. Ternary nonlinear regression method is used to estimate a function for predicting fat content by fat percentage.

4. **The Hardware Design.** The hardware of on-line detecting system mainly consists of image acquisition unit, transmission unit and processing unit. Though it is simple, it can capture high quality images and control the conveyor belt accurately.

4.1. **Image acquisition unit.** The main device in image acquisition unit is camera. Its performance parameters directly affect the systematical performance. We choose German AVT F-038 industrial camera, with resolution of 768×494 and 6 mm prime lens. When installing components, the camera need keep parallel with the beef sample to avoid the image distortion. It is set in light cover.

The light sources are also a component of this unit, which is fluorescent light and fixtures. Two soft and white LED are set besides the camera and inside the light cover. They are to provide sufficient light intensity for collecting image information.

4.2. **Transmission unit.** Transmission unit is mainly used to transport the beef samples and adjust its position for capture. This unit consists of the control circuit, stepper motor and conveyor belt. When it is working, the start/stop of the motor is controlled by the control circuit. The required space of grid on the conveyor belt is determined by the movement of the stepper motor and the size of the detected beef sample.

4.3. **Processing unit.** Processing unit consists of industrial personal computer (IPC) with detecting software. The computer is in charge of the coordination and operation of each part of the system, fulfills the tasks of the image acquisition, real-time processing and the output of the test results. This system selected Siemens SIMATIC IPC547eco industrial computer with image acquisition card, the Intel Pentium dual-core E5300 processor, 2 GB DDR2 800 memories, 800 GB SATA – HD 2.5 inch hard disk.

5. Experimental Results and Discussions.

5.1. Experimental materials. In this paper, the standard beef fat content is tested by Hydrote and Soxtec made in FOSS Company, which are regarded as the comparable data of detection result. Hydrote is used mainly for hydrolyzing experimental samples to avoid the error resulted from the traditional manual operation. Soxhlet extraction method was used for the standard value of fat content. This system can quickly and accurately carry out the total fat content detection, crude fat analysis and extractable matter.

The fresh beef samples were bought from supermarkets and farmers market. The purchased beef, which was washed with clean water and drained well, will be cut into uniform sliced meat about 3-5 mm thickness as 50 samples. They were put on dark blue background grid of conveyor belt in the system, captured and moved one next another.

5.2. Segmentation of fat and lean meat. For the sake of accuracy of region segmentation method, this paper studied and compared four segmentation algorithms including maximum entropy method, the minimal cross-entropy segmentation method, Otsu method and HSV color space segmentation method. In these algorithms, maximum entropy method, the minimal cross-entropy segmentation method and Otsu method employed R layer image in RGB color space to segment the image. While the process for HSV color space segmentation method is: converting the obtained RGB image into HSV image at first, then the Hue layer (H layer) is used to segment the fat and lean meat based on the optimal threshold that is to calculate the hue boundary threshold between the fat and lean area. The muscle tissues are the range of the hue component satisfying $H > 0.89$ or $H < 0.05$. Other hue components belong to fat area.

The results of four segmentation algorithms are shown in Figure 3. Figure 3(a) shows the image without background. Figures 3(b), 3(c), 3(d) and 3(e) are the fat area after segmentation as binary image based on minimal cross-entropy segmentation, Otsu segmentation, HSV color space segmentation and maximum entropy segmentation in sequence. The white areas in binary images are the fat areas. Figures 3(f) and 3(g) are the beef lean image without fat based on HSV color space segmentation and maximum entropy segmentation.

It can be seen from Figure 3: minimal cross-entropy segmentation and Otsu adaptive threshold segmentation are relatively poor in 3(b) and 3(c), while some lean areas are divided into fat areas. The segmentation effects of maximum HSV color space segmentation and entropy segmentation are better in 3(d) and 3(e). In addition, by comparing Figure 3(f) with 3(g), it can be seen that the fat areas are still larger than the real fat areas in Figure 3(f), but the fat areas in Figure 3(g) are much more accurate. Therefore,

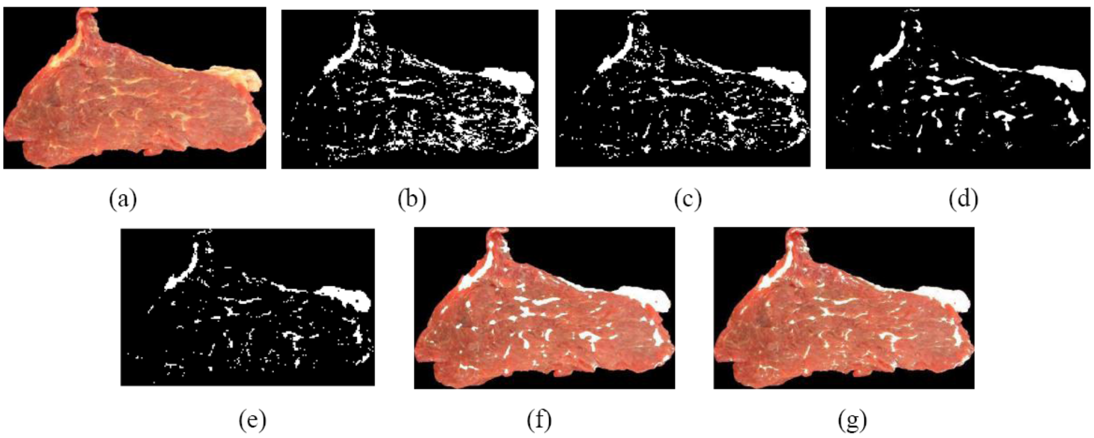

FIGURE 3. The segmentation results of separating fat and lean based on four methods

this experiment shows that the improved maximum entropy segmentation method can accurately segment the fat and lean meat in beef imaging.

5.3. **Fat content detecting results.** After the fat and lean areas are separated, the fat content of beef is calculated by Equation (4). HSV color space segmentation method and maximum segmentation method were all tested to estimate fat content. The data were analyzed and compared to get a better method. For showing the difference of fat content with the standard fat content by chemical method, Figure 4 shows the absolute differences by each sample. The x axis is the number of beef samples, and y axis is the difference value of predicting fat content and standard one. The unit of chemical results is g/100g, and we convert it into percentage that is easy for comparing. From Figure 5, the differences of fat content by maximum entropy method are much smaller than those of HSV color space segmentation method.

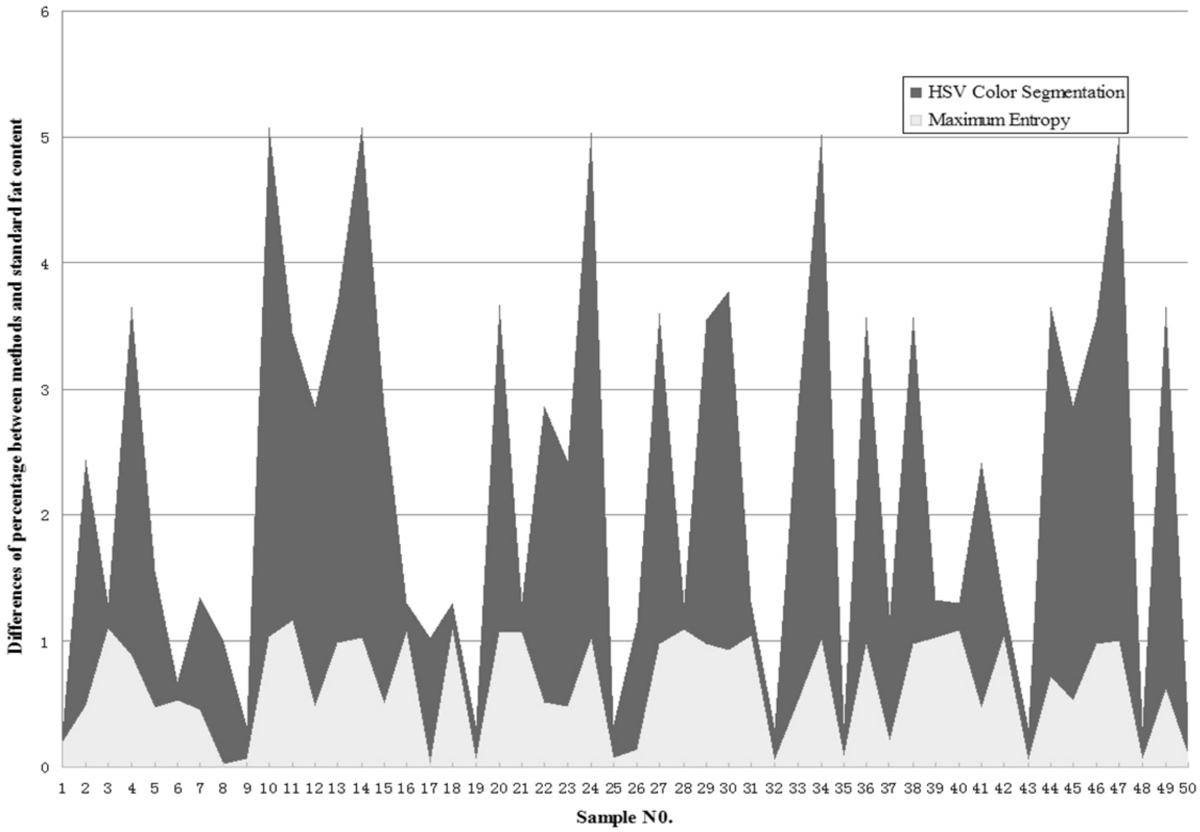

Figure 4. The differences of fat content with 50 samples

The detecting results and differences are also shown in Table 1. The first row of Table 1 is the average value of fat content under different detection methods. The second and the third rows are the maximum and minimum differences between the first two columns and the standard fat content tested by Soxhlet method. The last row is the total Euclidean distances of 50 samples. From this table, it can be seen that the smallest value in the last row is using maximum entropy method, and the difference is smaller than standard values. The results of maximum entropy method are better than HSV color space method among all the data.

Then, ternary nonlinear regression analysis method was applied to making the prediction results accurately. Figure 5 shows the results of nonlinear regression under two methods as y-axis. And the x-axis is the standard fat content percentage. Figure 5(a) fits the standard fat content by maximum entropy method, and 5(b) is HSV color segmentation method. In Figure 5(a), the data are closely distributed around the fitted curve

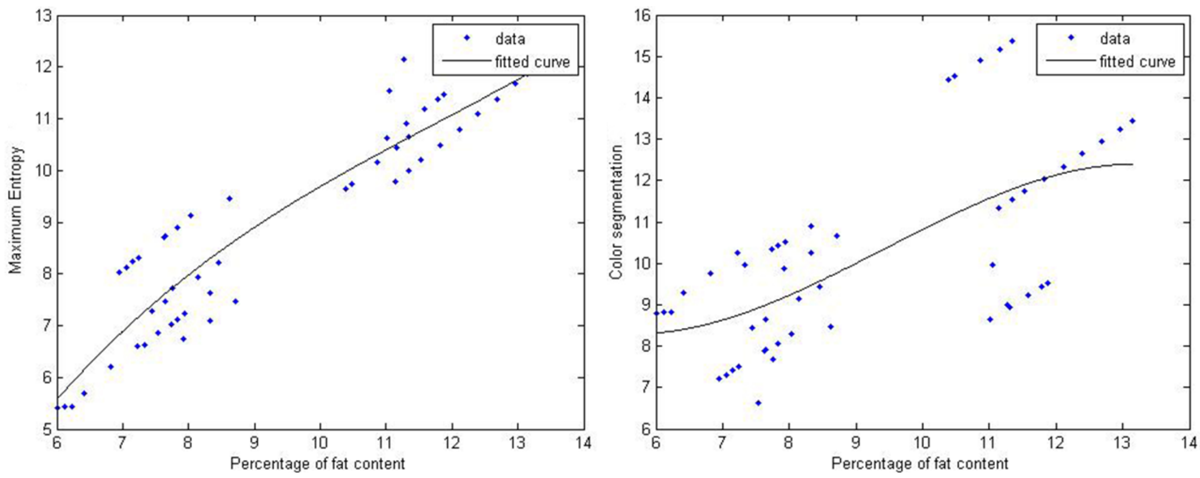

FIGURE 5. The results of ternary nonlinear regression

TABLE 1. The differences of fat content

Items	Maximum entropy	HSV color space	The fat content
Average	8.8162	10.1751	9.3870
Max	1.1326	5.0128	–
Min	0.0142	0.0705	–
Total	5.2342	14.7263	–

obviously, but they are distributed dispersively in Figure 5(b). Therefore, the maximum entropy method is more effective. The detective formula that is calculated by ternary nonlinear regression is as follows:

$$y = 0.0017x^3 - 0.1065x^2 + 2.528x - 6.532 \tag{5}$$

where y is the final detecting result of fat content percentage, and x is the fat content percentage that is calculated by maximum entropy method. In addition, the cube coefficient is very small, and the fitted curve in Figure 5(a) is like a quadratic curve. Therefore, the cube coefficient is eliminated for simplifying the formula, and the formula becomes as follows:

$$y = -0.1065x^2 + 2.528x - 6.532 \tag{6}$$

For testing the accuracy of the whole method and the on-line system of this paper, other 50 new samples were estimated by the proposed method and Soxhlet method. When the accuracy was calculated comparing two method results in the errors of 5% allowed, the accuracy of the proposed method was 92%. The detecting speed of on-line system was also tested, and the processing time is 0.83s per sample in average. It means that the system can process about 72 samples in one minute.

6. **Conclusions.** This paper presented an on-line non-destructive beef fat content detecting system including the hardware and software. The hardware design was introduced at first. Then, the software and the improved methods in it were mainly introduced and tested. A maximum entropy segmentation method was presented by employing R layer of image. It was proved to be the best method compared with other three segmentation methods including HSV color space segmentation method, minimal cross-entropy method and Otsu method. In addition, the fat content results estimated by the first two methods were also tested and compared with the results tested by Soxhlet extractor method. Experimental results show that maximum entropy method is accurate for isolating fat

and then computing fat content. A nonlinear regression function that approximated the standard fat content was calculated by the results of samples. Finally, by testing 50 new samples, the calculated result by maximum entropy method is in good agreement with the standard value by the accuracy of 92% and the detecting speed is 0.83s per sample. Therefore, the on-line detecting system can predict beef fat content quickly and accurately, and is suitable for practical use.

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