

Image analysis in computer vision: A high level means for Non-Destructive evaluation of marbling in beef meat

Adel Ziadi^{*}, Xavier Maldague^{*} and Linda Saucier^{**}

^{*}Electrical and Computing Engineering Department, adel.ziadi.1@ulaval.ca, Xavier.maldague@gel.ulaval.ca

^{**}Animal Science Department, linda.saucier@fsaa.ulaval.ca
Université Laval Québec (Qc), G1K 7P4, Canada

Abstract

Evaluation of meat quality by computer vision has been an ambitious area of research in recent years. Marbling (intramuscular fat tissue) in beef meat is one of the most important criteria for quality in meat grading systems. Chemical analysis, a destructive and expensive method, is the most frequently used for quantitative evaluation of marbling in beef meat. In this paper, a new Non-Destructive approach using computer vision is proposed as a possible alternative to the traditional chemical method. It is demonstrated that using near-infrared light in transmission mode, it is possible to detect not only the visible fat on the meat surface but also under the surface. Hence, in combining the analysis of the two sides of a meat sample, it is possible to estimate the overall percentage of marbling in this meat sample. The result of this new study showed that the proposed method is a valuable technique, thereby demonstrating the potential of implementing this approach in a vision system to quantify meat quality objectively.

Key words: Marbling, Non-Destructive, Image analysis.

1. Introduction

Meat quality in the Canadian beef cattle industry is a key element for success and consumer satisfaction. Moreover, it is in this context that the The Canadian Beef Grading Agency (CBGA) was created [1]. The CBGA was accredited by the Canadian Food Inspection Agency to provide services for grading (classification) carcasses for the beef industry. Marbling is the intramuscular fat (fat between the muscle fibres) which appears as visible white flecks. Sufficient marbling is important for beef tenderness, juiciness, and flavor. The size and distribution of marbling deposits have an important impact in terms of eating quality. The degree of marbling is the primary factor determining trade quality of meat. Generally, the greater the quantity and uniform distribution of marbling in the meat, the better the meat quality. For official grading purposes, marbling is assessed in the *Longissimus dorsi* muscle exposed between the 12th and the 13th ribs.

Traditionally, the grading process is visually (subjective) and performed by a trained person, called a grader. However, recently the use of artificial intelligence technology based on vision as an alternative solution (objective) to human intervention has generated considerable interest in the scientific community [2, 3, 4]. The main advantage to have this task performed by an artificial vision system is that it is objective in relation to human intervention (subjective). In addition, it is more economically viable because it is implemented in an automated system. However, these specific solutions are often to be developed on a case per case basis, hence are difficult to be generalized.

In the context of this study, we reviewed the different proposed methods to evaluate meat quality based on the marbling information in meat [5]. We can classify these methods into two categories: 1) methods based on the visible (VIS) information obtained from VIS images; and 2) methods based on both, VIS and near infrared (NIR) information, usually involving a signal coming from a spectrometry. In the first category, meat quality is typically graded by means of an analysis of the extent of marbling on the meat surface. These methods are still based on the local information obtained from the meat surface regardless of the sub-surface or internal composition of the meat (marbling or muscle), which could be different from the surface composition. In the second category, the spectrum of meat analysis is larger than the first method since the analysis is extended to the NIR spectrum. In this case, NIR light is interesting because it can easily penetrate into the muscle, or through the fat particles as it is reflected by the marbling (see Fig.1 for the schematic NIR light transreflectance mechanism through meat). Based on this property, NIR light is an interesting way to better characterize some properties of meat and its quality. On the other hand, intrinsic analysis of the meat content, i.e: proportion of the marbling versus muscle inside the meat sample is still an unsolved problem in computer vision.

To this end, following the line of research in our previous works [5], we introduced a new approach to estimate the volumetric marbling inside a beef meat sample. From this work, we demonstrated that using NIR light in transmission mode it is possible to show the marbling under the surface which cannot be detected by visual methods commonly proposed in computer vision [6]. Fig.1 illustrates this approach.

In this paper, an original Hybrid Artificial Vision System (HAVS) was developed to evaluate the volumetric proportion of the marbling in beef meat. This system benefits from the combined advantages of two systems, VIS and NIR (hybrid system). Hence, with the same camera working in the VIS and NIR bands, we obtained a VIS image of the meat surface similar to the traditional vision system [2, 3, 4], along with a NIR image of the marbling and muscle of the meat, under the surface as demonstrated in our work [5]. As shown in Fig.1, the NIR image (2D) obtained using the proposed method is the projection of the whole image of the meat sample (3D image), which means that the 3D shape (volume) of the marbling and muscle can be represented by a 2D image. However, since it is difficult to retrieve the 3D information from a 2D image using image processing in the NIR domain due to the loss of some information, it is interesting to combine the VIS and NIR images for this process. To the best of our knowledge, no scientific literature was found with respect to the use of NIR light in transmission mode for the evaluation of meat quality, and no proposed approach similar to ours was found for the evaluation of volumetric marbling in meat samples.

2. Experimental setup

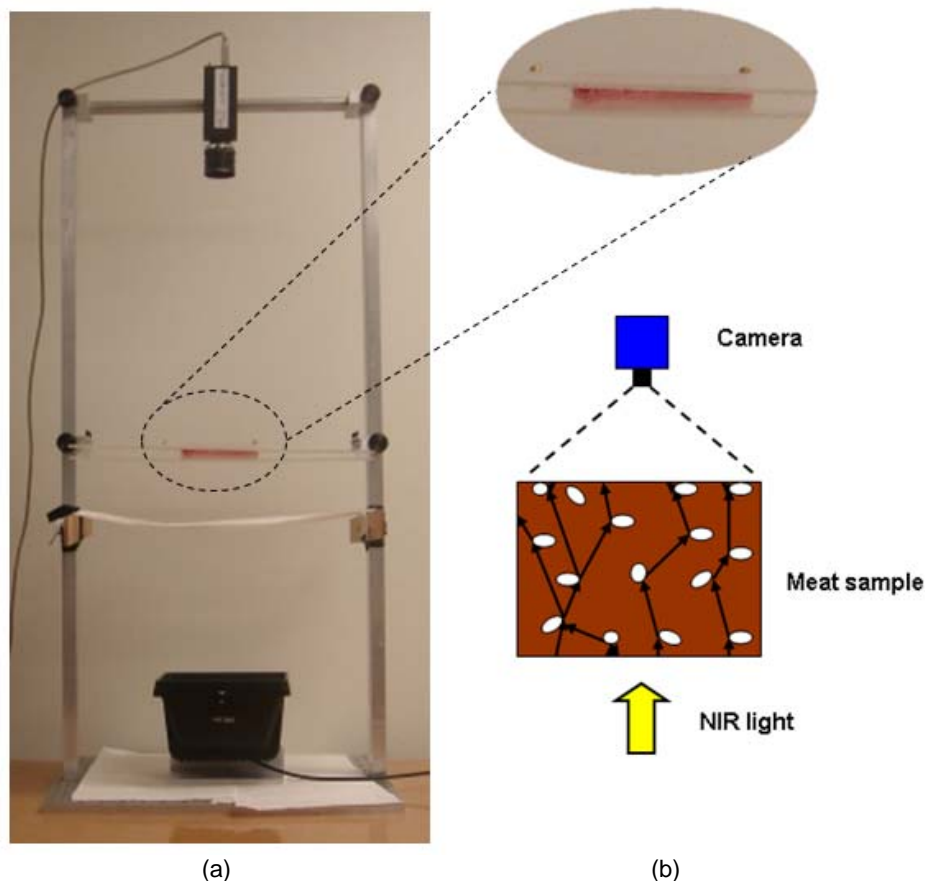


Fig.1. Proposed technique for the volumetric marbling estimation in beef meat (see text for details).
(a) HAVS experimental setup; (b) schematic NIR light transreflectance mechanism through the meat.

Fig.1b illustrates how NIR light is reflected or deviated by the fat particles through the meat sample before eventually reaching the opposite side of the meat sample. One objective of this work was to demonstrate the interest of applying the NIR light in transmission mode for the volumetric marbling estimation in beef meat. Hence, a HAVS was designed to that effect. Fig.1-(b) illustrates the experimental setup for the proposed system. It is composed of four elements: 1) a CCD Phoenix camera (MuTech Corporation) with a resolution of 1280x1024 pixels; 2) a device to keep the meat sample

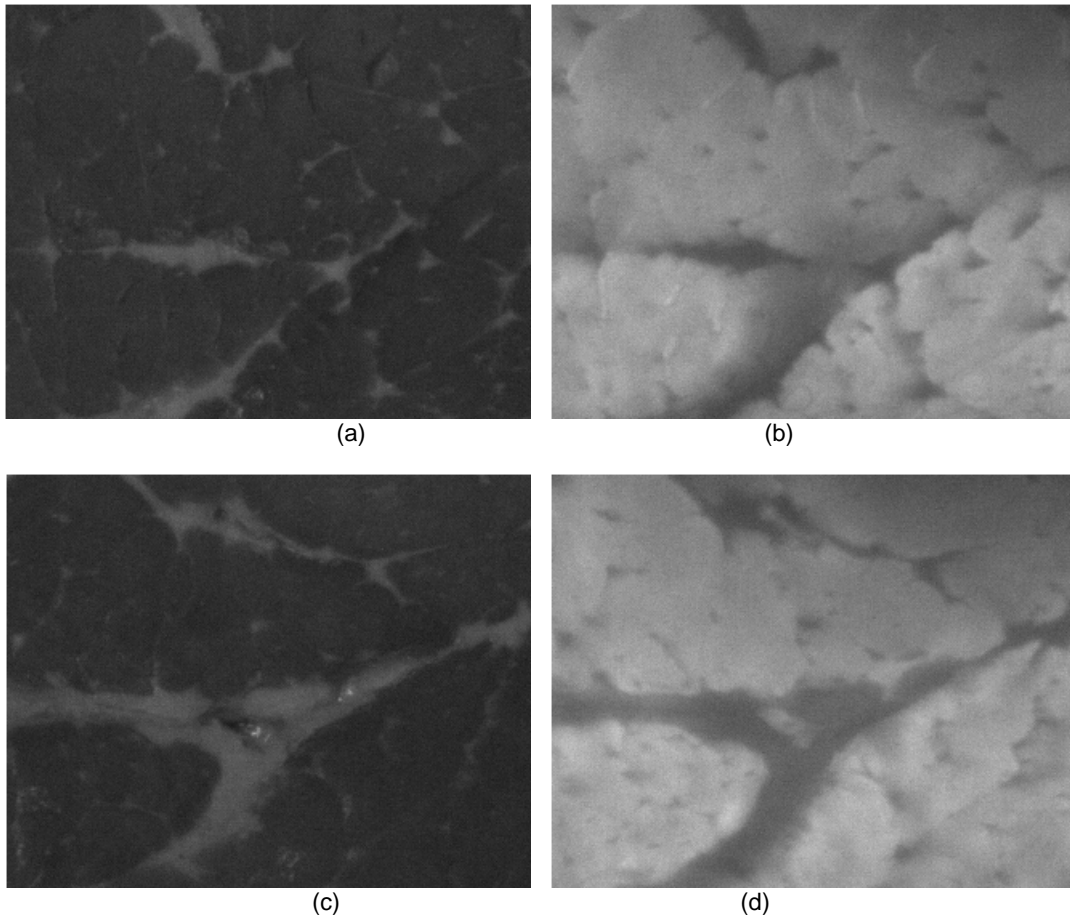
in front of the camera composed of two sheets of Plexiglas (transparent to NIR radiation). The plate below acts as a holder for the meat sample while the other is positioned on top to press the meat and to oriente the surface of the sample parallel to the CCD of the camera in order to maximize the amount of light reflected from the meat surface. Since it is difficult to obtain samples with a uniform thickness, the two plexiglas plates were attached together by screws in order to provide a sample with a more uniform thickness, thus improving the quality of the image obtained; 3) a light diffuser; and 4) a NIR light source. During the experiments, two types of light sources were used. For VIS images acquisition (reflection mode), fluorescent lighting mounted on the ceiling of the laboratory was used. However, for the NIR acquisition (transmission mode), a NIR light projector of wavelength 940 nm was used, which was considered as an optimal source for our experiments. Finally, in order to use the same camera, in the same position, for both types of acquisitions, the NIR filter of the camera has been removed. This strategy has the advantage to keep the same resolution and registration for both images and thus to have a more robust system.

Experiments were performed on beef muscle from the *Longissimus dorsi* of Angus AAA beef. The *Longissimus* was obtained from a specialized butcher shop and sliced in samples of about 5.5 to 6.5 mm thickness.

3. Marbling isolation using VIS and NIR images segmentation

Marbling isolation (or detection) in meat samples is an important stage of the intramuscular fat volumetric estimation process. This step consists in the segmentation of the fat particles observed in the VIS and NIR images. Hence, it is the first stage on which to base the rest of the process. Of course, the global performance of the volumetric estimation method of the marbling could not be guaranteed without the performance of a segmentation stage.

In this paper, we use our own image segmentation method which was developed specifically for this application (unpublished data). Fig.2 shows VIS and NIR images obtained using the proposed acquisition system presented in Fig.1. All images (four images) are in gray-level intensities, two images for every face of the meat sample, one in the VIS domain and the other in the NIR domain at 940 nm. Segmentation results for the four images using our method are illustrated in Fig.3. This figure shows that, contrary to the VIS image in which the marbling is segmented based on its gray-level on the meat surface, in the case of the NIR image, marbling should be segmented (isolated) from its shadow inside the meat. As shown in Fig.3-(b), the segmentation process is not an easy task; it is more complex than the segmentation of the VIS image. In fact, the complexity is due to several phenomena, which contribute to the low contrast variation between the marbling and the muscle. For instance, the varying thickness of the meat sample, which is one of the major problems encountered during the experiments, and also the mechanism of light transmission through the sample of meat. In this paper, we will not examine the segmentation method of marbling in detail since this is not the primary goal of this particular research work. Hence, segmentation results are illustrated in the Fig.3.



(a) face 1 VIS image; (b) face 1 NIR image (940 nm);
(c) face 2 VIS image; (d) face 2 NIR image (940 nm).

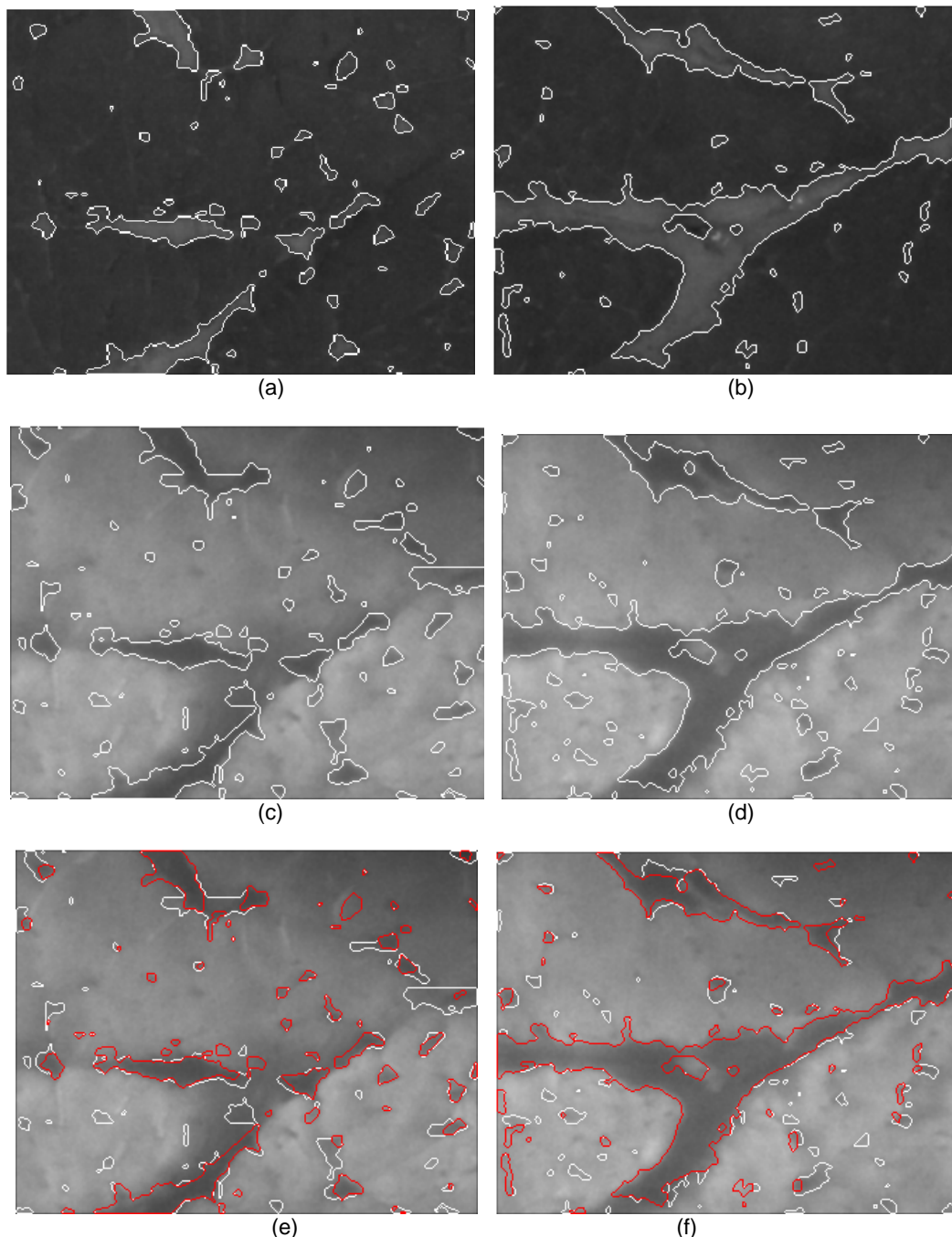


Fig.3. Marbling isolation using VIS and NIR images segmentation.
(a) face 1 VIS image; (b) face 1 NIR image;
(c) face 2 VIS image; (d) face 2 NIR image ;
(e) face 1 VIS (red) and NIR image; (f) face 2 VIS (red) and NIR image.

4. Models and proposed method

In our previous study [5] and above, we showed that NIR images of the meat samples are rich in information about the intrinsic composition of meat such as water, proteins (lean muscle) and fat. Also, as shown in Fig.3, information contained in the VIS image is also retrieved in the NIR image since the NIR image is the projection of the shadow of all

marbling of the meat sample (3D representation in 2D). Hence, the study of NIR image content allows the extraction of detailed information of all marbling under the meat surface. Based on the geometric shapes of the marbling regions, it is possible to establish the relationship of the distribution and connectivity of the marbling at different levels of the meat sample depth. The process leading to the realization of this task is a process of pattern recognition that is in itself a large research field of computer vision [7, 8].

To our knowledge, there is no report published so far describing the geometric shape or pattern of fat deposition that leads to the evaluation of marbling of the lean muscle. Specifically, there is no scientific literature describing if the fat deposit follows a particular geometric shape, i.e: conical, cylindrical or otherwise. On the other hand, based on our observations and experimental research on this topic [9, 10], fat particle shapes leading to marbling regions are rather formed at random: spherical, conical, ellipsoid or any other complex shape. However, based on our observation, for the small isolated regions, these could be modelled by an ellipsoid shape having the same or equivalent surface as the original shape. When two regions match between face 1 and face 2 of the meat sample, marbling could be modeled by a conical shape with two bases whose surface corresponds to the relevant surfaces of two regions observed in face 1 and 2. In this paper, we limited the description of the adopted process to an initial estimate of the volumetric marbling in the meat sample. This estimate is conducted in the minimal and maximal volumetric proportion of the marbling in the meat. Fig.4 shows a 3D illustration of the two faces of the meat sample.

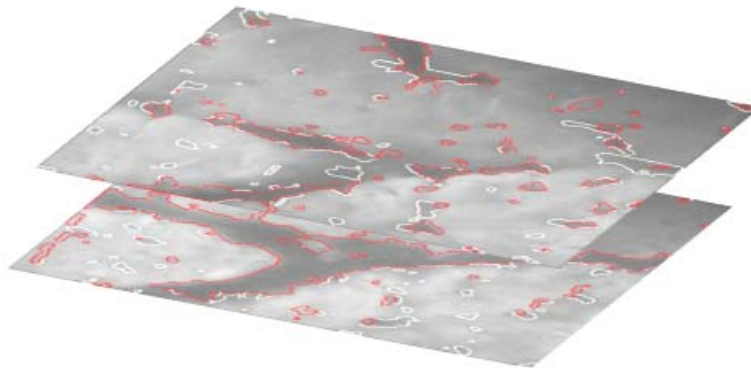


Fig.4. 3D illustration the two faces of the meat sample.

To simplify the initial estimation process, small regions were not taken into consideration (regions having a surface of less than 1.5 mm^2). The volumetric region is calculated according to the obtained shape described by equation 1. Fig.5. shows an illustration of the 3D geometric model.

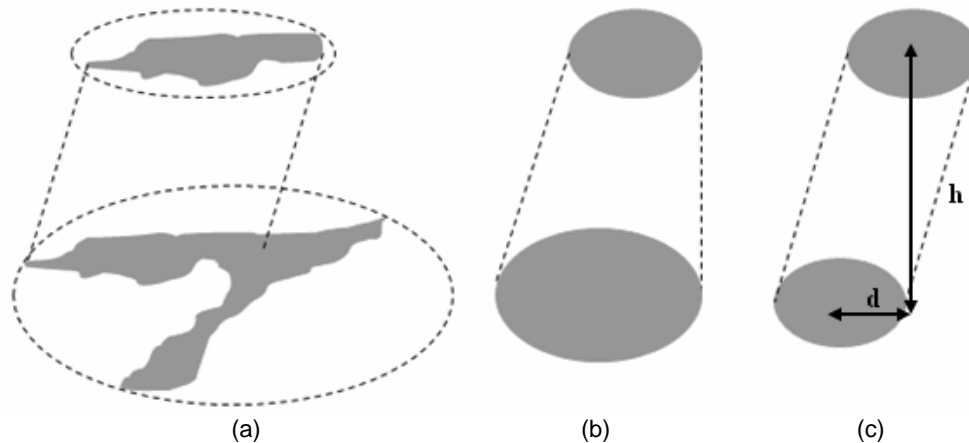


Fig.5. Model of the two matched regions.
 (a) real regions to be matched; (b) modeling regions in ellipsoid shape; and
 (c) matched regions.

$$V = A * \sqrt{h^2 + d^2} \quad (1)$$

where: V is a volumetric marbling matched the two regions; A is the area of the small region of the two matched regions in the face 1 and face 2; h is meat sample thickness; and d is the distance between the two regions center.

The proposed method of initial volumetric marbling assessment of the beef meat sample can be summarized as follows:

- a) Isolate the marbling observed in VIS and NIR images using image segmentation, an example is shown in Fig.3. At this stage, marbling regions on the surface of the meat are identified based on results of the VIS image segmentation;
- b) From the results obtained in a), identify the marbling regions just under the surface (close the surface) in the NIR image. These regions will then be merged to the marbling regions on the surface detected using VIS image;
- c) Map the marbling regions crossing the entire thickness of the meat sample, this could be done using a pattern recognition method;
- d) Calculate the volumetric marbling of all matched regions as described in equation 1. At this stage, the minimum volumetric marbling in the meat sample is estimated.
- e) Calculate the minimum volume of the muscle by adding the pixels of the muscle observed simultaneously (same pixel position) in both NIR images of face 1 and 2; adding 2/3 for each pixel of muscle observed only using NIR image of face 1 or face 2 (See Fig. 4).
- f) From the results obtained in e) and using the volume of the meat sample, calculate the maximum volumetric proportion of the marbling in the meat sample.

5. Results and discussion

Experiments were performed on 15 samples of *Longissimus dorsis* muscle of Angus AAA beef according to the CBGA grading system [1]. The samples thickness was about 5.5 to 6.5 mm. For every sample, VIS and NIR images were obtained under the same conditions for both faces: VIS images were obtained using the fluorescent lighting; NIR images were acquired using a projector light at 940 nm in transmission mode. Hence, we have 60 images in our data base. Table 1 shows the results obtained.

Table 1. Percentage estimation of the marbling in beef meat following our proposed algorithm

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Av
Min (%)	12	7	9	7	6	5	10	2	8	11	15	16	14	9	4	9
Max (%)	31	25	27	22	23	21	26	21	29	33	41	40	34	19	17	27

Av: average.

Table 1 shows the results obtained for the minimum and maximum volumetric percentage of marbling estimated for the 15 samples. The range of the volumetric marbling of the meat samples is estimated at 9 to 27 % of the volumetric meat sample. Garcia et al. [11] predicted the percentage of intramuscular fat in beef *Longissimus dorsi* muscle classified as "Prime" with respect to the U.S Department of Agriculture (USDA) grading system [11], which is equivalent to AAA grade in Canada. In this study, the predicted minimum and maximum values of marbling ranged between 7.09 and 18.32%, which demonstrates that our estimation is in accordance with the recognized grading system.

6. Conclusion

In this paper, a new Non-Destructive method using computer vision is proposed to estimate the volumetric intramuscular fat percentage in beef referred to as marbling. It is demonstrated that using NIR light in transmission mode, it is possible to detect not only the visible fat on the meat surface but also underneath the surface. Hence, an original Hybrid Artificial Vision System is described. Preliminary results of the proposed method are presented as the minimum and maximum volumetric estimation of the marbling in meat samples. The results obtained are in agreement with the samples AAA grade and with similar studies. The proposed method is a potential attractive alternative method to the cumbersome traditional chemical (destructive) method.

REFERENCES

- [1] <http://www.beefgradingagency.ca>, (consulted in April, 2010).
- [2] F. Yoshikawa, K. Toraiichi, K. Wada, N. Ostu, H. Nakai, M. Mitsumoto, K. Katagishi, "On a grading system for beef marbling", *Pattern Recognition Letters*, Vol. 21, pp.1037-1050, 2000.
- [3] J. Lu, J. Tan, P. Shatadal, D.E. Gerrard, "Evaluation of pork color by using computer vision", *Meat Science*, Vol. 56, pp. 57-60, 2000.
- [4] J. Tan, "Meat quality evaluation by computer vision", *Journal of Food Engineering*, Vol. 61, pp.27-35, 2004.
- [5] A. Ziadi, X. Maldague, L. Saucier, "Near-Infrared Light Transmission in Beef Meat and Qualitative Marbling Evaluation Using Image Analysis", *ICGST International Journal on Graphics, Vision and Image Processing, GVIP*, Vol. 9, No: 6, pp: 7-12, 2009.
- [6] W.K. Pratt, *Digital Image Processing*, 2nd Edition, 1991, 698 p.
- [7] L. Huang, M. Wang, "Efficient shape matching through model-based shape recognition", *Pattern Recognition*, Vol. 29, No. 2, pp:207-215, 1996.
- [8] H. Zaboli, M. Rahmati, A. Mirzaei, "Shape recognition by clustering and matching of skeletons", *Journal of computers*, Vol.3 No.5, pp:24-33, May 2008.
- [9] X. J. Yang, E. Albrecht, K. Ender, R. Q. Zhao and J. Wegner, "Computer image analysis of intramuscular adipocytes and marbling in the longissimus", *Journal of Animal Science*, Vol. 84, pp: 3251-3258, 2006.
- [10] B. Lebret, L. Lefaucheur, J. Mourot, "La qualité de la viande de porc, Influence des facteurs d'élevage non génétiques sur les caractéristiques du tissu musculaire", *INRA Prod. Anim.*, Vol. 12, No. 1, pp: 11-28, 1999.
- [11] L.G. Garcia, T.E. Lawrence, T.H. Montgomery, D.B. Parker, M.S. Brown, "The Prediction of Fat Percentage in the Longissimus Dorsi Muscle in Fed Beef Using Nuclear Magnetic Resonance", *Journal of Muscle Foods*, Vol completion, Vol. 17, pp:375-380, 2006.