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Abstract

Real-time ultrasound images from the Longissimus dorsi muscle across 11th to 13th ribs of 720 live bulls and steers were acquired over the period of four years. The actual intramuscular percentage of fat (IFAT) was determined using an n-hexane extraction with mean of 4.98%, standard deviation of 2.12%, and range from 1.10% to 14.68%. Image-processing techniques were used to calculate parameters to quantify the image texture patterns. The parameters which showed good correlations with the actual IFAT were used to develop a statistical linear regression model. The accuracy of prediction was very good for the actual IFAT less than or equal to eight (low IFAT group), with root mean square error (RMSE) around 1.0%. However, the model was much less accurate for prediction of IFAT values more than eight (high IFAT group), with RMSE more than 1.5%. One reason for this could be the limited ability of the ultrasound technique to resolve differences in high-IFAT muscles in terms of image texture patterns. Also, this group contained fewer than 10% of the images collected, which may be an inadequate sample. Overall accuracy of prediction was improved by developing different regression models for the low-IFAT and high-IFAT groups. Statistical pattern recognition and classification techniques were applied to "pre-classify" the images into low- or high-IFAT groups before being subjected to regression prediction models. The techniques applied included cluster analysis, discriminant analysis, and classification and regression tree (CART). The classification tree provided the best results with overall classification accuracy around 90% for low- and high-IFAT groups of images. In conclusion, overall accuracy of predicting the IFAT from ultrasound image parameters and regression models can be improved by first isolating the high- IFAT group from low-IFAT group using statistical classification methods.

Keywords

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Application of Statistical Methods for Improving Models of Intramuscular Percentage Fat Prediction in Live Beef Animals From Real-Time Ultrasound Images

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Summary

Real-time ultrasound images from the *Longissimus dorsi* muscle across 11th to 13th ribs of 720 live bulls and steers were acquired over the period of four years. The actual intramuscular percentage of fat (IFAT) was determined using an n-hexane extraction with mean of 4.98%, standard deviation of 2.12%, and range from 1.10% to 14.68%. Image-processing techniques were used to calculate parameters to quantify the image texture patterns. The parameters which showed good correlations with the actual IFAT were used to develop a statistical linear regression model. The accuracy of prediction was very good for the actual IFAT less than or equal to eight (low IFAT group), with root mean square error (RMSE) around 1.0%. However, the model was much less accurate for prediction of IFAT values more than eight (high IFAT group), with RMSE more than 1.5%. One reason for this could be the limited ability of the ultrasound technique to resolve differences in high-IFAT muscles in terms of image texture patterns. Also, this group contained fewer than 10% of the images collected, which may be an inadequate sample. Overall accuracy of prediction was improved by developing different regression models for the low-IFAT and high-IFAT groups. Statistical pattern recognition and classification techniques were applied to "pre-classify" the images into low- or high-IFAT groups before being subjected to regression prediction models. The techniques applied included cluster analysis, discriminant analysis, and classification and regression tree (CART). The classification tree provided the best results with overall classification accuracy around 90% for low- and high-IFAT groups of images. In conclusion, overall accuracy of predicting the IFAT from ultrasound image parameters and regression models can be improved by first isolating the high-IFAT group from low-IFAT group using statistical classification methods.

Introduction

Iowa State University's Department of Animal Science has conducted extensive research into ultrasound evaluation of beef quality. Statistical models have been developed for predicting intramuscular percentage of fat (IFAT) in the *Longissimus dorsi* muscle of live beef cattle using real-time ultrasound images. Several image and signal processing techniques and statistical methods have been applied for developing the prediction models. The developments over last few years have been reported in Beef Research Reports. In general, predicted IFAT values show good accuracy with root-mean-square error (RMSE) between 1.0% and 1.5% using regression models. Application of statistical and pattern recognition methods for "pre-classifying" images into high- and low-IFAT groups show promise of further improving the accuracy. This report describes several newer techniques and approaches for improving the accuracy and robustness of the prediction models.

Materials and Methods

Real-time ultrasound images from the *Longissimus dorsi* muscle across the 11th to 13th ribs of 720 live bulls and steers were acquired over a period of four years. The actual IFAT from a slice of each muscle scanned was determined using an n-hexane extraction method. Image-processing techniques were used to calculate parameters to quantify the image texture patterns. The parameters which showed good correlations with the actual IFAT were used to develop a statistical linear regression model.

The regression model for prediction of IFAT was developed using a randomly selected development set of 392 images and a validation set of 318 images, both with similar distributions of IFAT. The residual errors of prediction were reported for the full range as well as for smaller ranges of IFAT. The accuracy of prediction was analyzed for IFAT less than or equal to eight (low-IFAT group) and for IFAT more than eight (high-IFAT group).

In order to improve the overall accuracy of prediction, different regression models were developed for the low-IFAT and high-IFAT groups. Also, statistical pattern recognition and classification techniques were applied to classify the images into the low- or high-IFAT groups. These techniques included cluster analysis, discriminant analysis, and classification and regression tree (CART).

The cluster analysis is an unsupervised classification technique which attempts to divide the given dataset into a given number of clusters so that the variances among the clusters are more than the variances within the clusters. For ultrasound data, cluster analysis was applied for finding two clusters using one or more image texture parameters. Then, the clusters were studied for their characteristics for IFAT ranges. If the clusters were well classified around certain value of IFAT, then the technique was considered useful for "pre-classification" of IFAT ranges.

The discriminant analysis is a supervised classification technique which uses the actual IFAT values in the development of the linear classification model. It iteratively "learns" the linear rule from the training samples so that the chance of misclassification is made as small as possible. This technique was applied to develop the rule for classifying images into the low-IFAT and high-IFAT groups using 354 images, and the rule was tested using a different set of 354 images. Several such randomly selected development and testing sets were analyzed for accuracy of classification.

The CART is a supervised learning technique which provides a non-linear classification model in the form of a binary tree. Each node of the tree checks the value of a parameter and jumps to one of two sub-nodes based on the conditional check with the node coefficient (e.g., is parameter P1 greater than coefficient 31.05?) Such a tree ends at each branch with a classification result. This technique also was applied to develop the tree for classifying images into the two IFAT groups using 527 images, and the tree was tested using a different set of 132 images.

Results and Discussion

The actual IFAT values for 720 animals scanned ranged from 1.10% to 14.68% with a mean of 4.98% and a standard deviation of ±2.12%. This range covered all four USDA quality grades: Prime, Choice, Select, and Standard.

The regression model for prediction of IFAT was developed using a randomly selected development set of 392 images and a validation set of 318 images, both with similar distribution of IFAT. For the full range of IFAT, the RMSE of prediction was 1.41%, coefficient of determination (R-square) was .60, and the Pearson's coefficient of correlation between the predicted and the actual IFAT was .60. For regression of predicted versus actual IFAT, the intercept and slope were .51% ($p > .1$) and .98 ($p < .001$), respectively. The distribution of the absolute residual means for four ranges of IFAT are shown in Table 1. The accuracy of prediction was very good for the lower actual IFAT. However, the model was much less accurate for prediction of IFAT greater than 8% or 9%.

Correlation analysis of the selected parameters with the IFAT showed significant differences between the low- and high-IFAT groups. Table 2 presents examples of correlation coefficients for the full range, the low-IFAT group, and the high-IFAT group. As seen from the table, the correlations were not significant for IFAT greater than 8%. However, they were significant between 7% and 8% IFAT. One reason for this could be the limited ability of the ultrasound technique to resolve differences in high-IFAT muscles in terms of image texture patterns. Also, this group contained fewer than 10% of the images collected, which may be an inadequate sample.

Cluster analysis using a Fourier transform-based texture parameter showed great potential for accurately isolating images of the low-IFAT group. For the calculated value of a Fourier texture parameter less than -5.6 (Cluster 1), about 96% of the images belonged to the low-IFAT group. However, this accounted for only 65% in the low-IFAT group. The other cluster (Cluster 2) had IFAT values scattered across the full range. Two different regression models were developed and tested using the images in the two clusters. The validation results for Cluster 1 and Cluster 2 models are presented in Table 3. The accuracy of prediction was very good for Cluster 1, with an RMSE of 1.13%. However, the model was less accurate for prediction of IFAT values in Cluster 2, with an RMSE of 1.51%. These results encouraged further development of the classification approach to improve the overall accuracy of prediction.

Table 1. Absolute residual means and standard deviations for the validation testing of the regression model for four different ranges of the IFAT.

IFAT (%)	N	Mean (%)	SD (±%)
0-3	57	1.03	.66
3-6	183	.85	.66
6-9	68	1.65	1.09
> 9	10	5.32	1.82

Table 2. Correlation coefficients of selected image parameters with different ranges of IFAT.

Parameter	1-14% (N=708)	<= 8% (N=640)	> 8% (N=68)
FRP11	.56 ($p < .001$)	.50 ($p < .001$)	.06 ($p > .5$)
FRP2	.51 ($p < .001$)	.47 ($p < .001$)	.11 ($p > .3$)
FI3	.45 ($p < .001$)	.36 ($p < .001$)	.07 ($p > .5$)

Discriminant analysis using three image texture parameters showed a classification accuracy of 88% for the high-IFAT group and 74% for the low-IFAT group. Results of one validation test of this approach using 354 images and five Fourier image parameters is shown in Table 4, with an overall misclassification rate of 16%. The results from several randomly selected training/testing groups showed misclassification rates between 14% and 25%.

The CART technique developed the classification rule in the form of a tree as illustrated in Figure 1. A tree for five parameters was developed using 527 images and tested using 132 images. The misclassification rates for five randomly selected sets of training/testing were 11%, 10%, 8%, 6%, and 8%. Results from several randomly selected sets showed misclassification rates between 3% and 20%. Thus, the CART technique provided better results than the discriminant analysis for classification. More parameters applying newer techniques in image processing are being used to develop the classification tree to more accurately group images into two classes before subjecting them to the regression prediction models.

In conclusion, overall accuracy of predicting IFAT from ultrasound image parameters and regression models can be improved by first isolating the high-IFAT group from the low-IFAT group using statistical classification methods.

Table 3. Validation statistics for regression models developed from two clusters of ultrasound dataset.

	RMSE	R-square	Intercept	Slope	Correlation
Cluster 1	1.13	.44	.004	1.03	.60
Cluster 2	1.51	.52	.57	.92	.65

Table 4. Discriminant classification validation using five Fourier image parameters.

Actual IFAT	Predicted > 8% IFAT	Predicted <= 8% IFAT	Total
> 8%	33 (97%)	1 (3%)	34 (100%)
<= 8%	90 (28%)	230 (72%)	320 (100%)
Total	123 (35%)	231 (65%)	354 (100%)

This hierarchical approach will provide more accurate and robust prediction than just applying a general regression model.

Implications

The proposed technique will provide improved IFAT prediction accuracy from ultrasound images. Most of the cattle scanned have IFAT less than 8% or 9%, and "pre-classification" into the low- or high-IFAT groups will improve the results of prediction significantly. This approach also provides the possibility of improving the accuracy of prediction for bulls which tend to have lower IFAT.

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Figure 1. Illustration of the classification and regression tree rule for classification of images into groups of less than 8% and more than 8% IFAT.