CHAPTER 3

ON-LINE PORK CARCASS GRADING WITH THE AUTOFOM ULTRASOUND SYSTEM

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ABSTRACT

On-line pork carcass grading with the Autofom ultrasound is described. The system consists of 16 ultrasound transducers positioned in a frame. The carcass is measured fully automatic at 3,200 positions in a depth of approximately 12 cm with a depth resolution of 0.19 mm. The ultrasound data forms a three-dimensional ultrasound image, which is processed for noise reduction, orientation detection and extraction of 127 features describing the carcass composition. The image features are used in a multivariate data regression model, which is used for on-line predictions. On-line tests performed at line speeds up to 1,150 carcasses/h, provide predictions of the meat percentage with an accuracy of 1.58 to 1.95%. Good predictions of the fat thickness and primal meat cuts have also been made.

INTRODUCTION

The use of fast acquisition techniques and computer analysis is rapidly improving carcass grading. For pig carcass evaluation, modern approaches such as the Tobec scanner and the Danish Classification Center may replace manual approaches such as the Fat-O-Meater, the Henessy or manual rulers (see Swatland 1995 for a review of these instruments).

Ultrasonic approaches have been investigated extensively during the recent years. This technology posses the advantage of being fast and non-invasive. Gresham et al. (1992) and Akridge et al. (1992) both used manual ultrasound equipment for measuring minimum fat thickness on pig carcasses. Similarly, Liu and Stouffer (1995) used a manually serviced medical ultrasound scanner for acquiring ultrasound images at specific positions in the carcass. Using image analysis the image was processed automatically, and the information was subsequently used in an on-line carcass grading situation.

The latest approach in carcass classification instruments is the Autofom system introduced by SFK Technology in 1995 (Brøndum 1995) and approved for classification in Denmark in 1996 (Busk and Olesen 1996). This system utilizes the ultrasound technique for scanning the animal, but in contrast to the above described probes and Aloka approach, the scanning of the total carcass body is fully automatic. The objective of this article is to present a technical description of the system and describe the results of on-line tests performed at normal line speeds at four different plants.

MATERIALS AND METHODS

Autofom Ultrasound System

The Autofom ultrasound system consists of four main modules: the ultrasound transducer array, the acquisition module, the data processing workstation and a personal computer. The animals are automatically pulled through the array by the conveyor as illustrated in Figure 1. The transducer array is designed to anatomically fit the back of the carcass as illustrated in Figures 1 and 2. The scanning is initialized automatically by the acquisition module when a sufficient signal on the transducer is registered. The automatic triggering is possible due to the fact that ultrasound transmits poorly through air, but well through skin. Therefore, the signal intensity is strongly increased when the animal is pulled over the array. Triggering on several transducers simultaneously reduces the risk of "false starts" which can occur, for example, with water or dirt on the array. The automatic pulling of the carcass, triggering of the measurement and the subsequent data analysis removes all need for manual operation in the system.

The animals are seldom totally symmetrically oriented in the frame as shown in Figure 2. But the midline and one side of the carcass is always measured. Due to the symmetric state of the animal measuring the midline and one side of the carcass is assumed sufficient (Bowman 1962 and Lasby 1957).

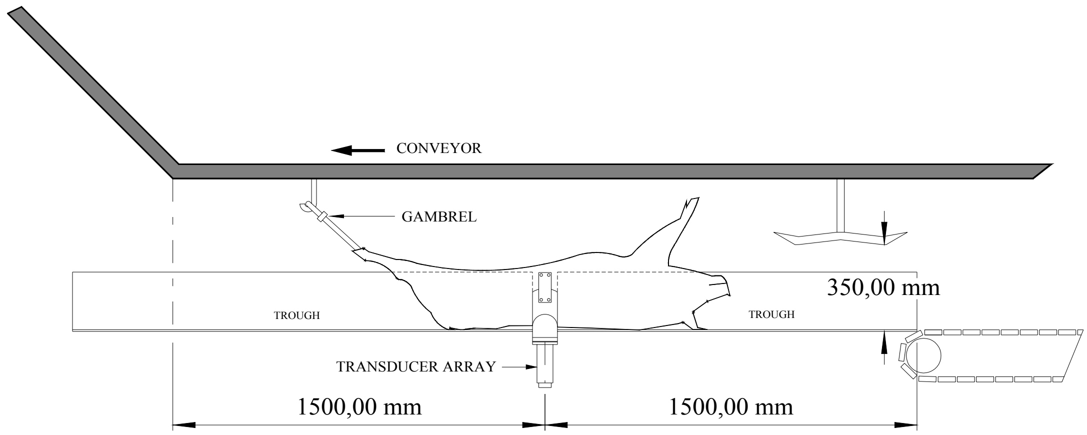

Figure 1. The carcass is pulled over the frame with 16 ultrasound transducers.

The non-invasive pulse/echo ultrasound mode is used for signal generation. The same transducer is used for both transmission and reception of the ultrasonic signal as illustrated in Figure 3a. Each transducer transmits a sound pulse and switches to receiving mode. The transmitted sound burst is reflected in the carcass mainly by transitions between different kinds of biological tissue, caused by different acoustic impedance of the tissues. High signal intensities is measured when the echo of burst is reflected from the intersections between the tissue types. By registering the received echo signal as a function of time an A-scan is obtained as illustrated in Figure 4. The illustration in Figure 4 corresponds to transducer 6 from Figure 2.

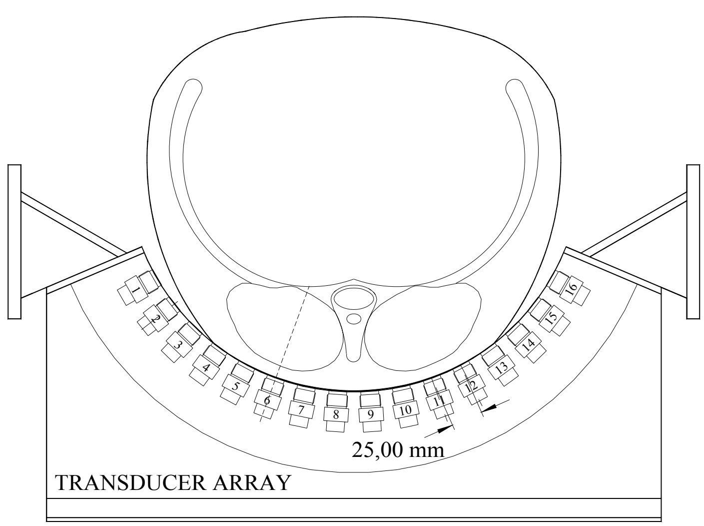

Figure 2. The ultrasound transducers are positioned with a distance of 25 mm. thereby covering most of the back of the animal.

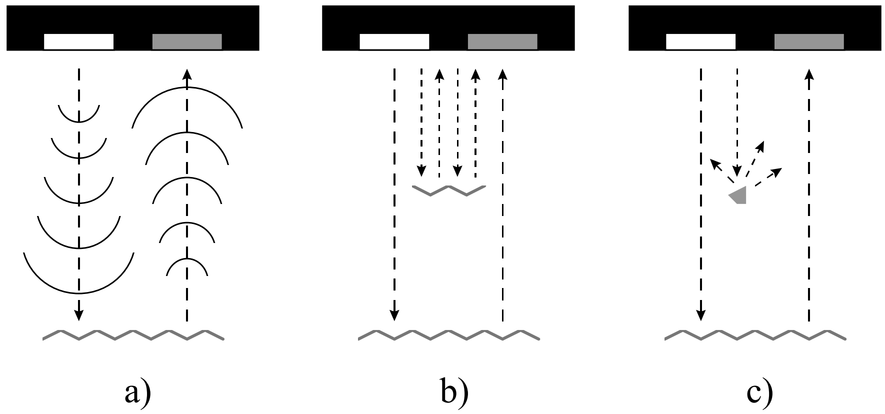

Figure 3. a) The pulse echo ultrasound principle is used. b) Double reflection may appear as false signals. c) Scatter occurs at reflections from small objects.

Figure 4. An ultrasonic A-scan displays the echoes as a function of time. High intensities occur at intersections between different tissue types as e.g. the fat/meat intersections to the left and the muscle/rib intersection to the right.

In the carcass the outer layers consist of fat and the next layers consist of meat. Hence the first echoes observed originate from the intersection between the fat layers and the meat. Subsequent echoes originate from the intersection between the meat and the ribs. This is illustrated in Figure 4, which shows a theoretical example of an A-scan in the middle of the loin (see transducer number 6 in Figure 2). The outer fat layers are observed as intensive peaks to the left. Deeper in the carcass follows a constant meat region with weak or no reflected echoes. Echoes in this region may occur from marbling in the meat. To the right on the A-scan the transition from the meat to the ribs is clearly observed as strong peaks.

A pulse frequency of 2 MHz is used resulting in a .5-μs time interval between the samples. Using the sound velocity in fat from Table 1, this results in a depth resolution of .36 mm (note that the distance is traveled twice before the echo is received). Similarly, using the sound velocity in meat, a resolution of .395 mm is observed. For each measuring position, the sampling period is 127 μs. Thereby, a depth of 9.14 cm is reached if the sample consists of pure fat and 10.03 cm if the sample consists of pure meat (estimated using the velocities in Table 1). In the current setup each of the

16 transducers perform 200 A-scans longitudinally with a distance of 5 mm (totally 3,200 A-scans). Combination of the 200 A-scans performed by one transducer results in a transducer image of the length profile of the carcass. For each carcass 16 of such transducers images are created and the total ultrasound scanning process thereby form a three-dimensional image of the carcass.

One of the disadvantages of the ultrasound technology is the low ratio of signal to noise. Two types of noise in ultrasound data are dominant: double reflections and scattering. Double reflections occur at high intensity echoes. After reaching the transducer the sound burst is reflected and echoed back a second time. Hence the double reflected echo is received at twice the time as the first echo. The principle in double reflections is illustrated in Figure 3b. Ultrasound scatter occurs by reflections from small objects (e.g., intramuscular fat) and appears as a ‘salt’ noise in the ultrasound images. The principle is illustrated in Figure 3c. The noise level requires special attention when processing ultrasound images.

Table 1. Sound speed and acoustic impedance for different biological materials (Jacobson, B. 1987)

Material	Sound speed (m/s)	Acoustic Impedance $kg/(m^2s)*10^{-6}$
Air	330	0.0004
Fat	1,440	1.37
Muscle	1,580	1.69
Bone	4,000	6.80

DATA ANALYSIS

In an on-line functioning system two phases exist in the data analysis. The first is the calibration phase, where the data processing is optimized and the regression models for the future predictions are calibrated. The calibration takes place prior to the actual on-line use. The second phase is the prediction phase, where the optimized data processing and prediction takes place at on-line speeds.

The data processing in the Autofom system is separated into two steps: the image analysis (and feature extraction) and the multivariate regression analysis. The image processing is performed both in the calibration and in the prediction phase. The data analysis that concerns the construction of the regression models is performed in the calibration phase only. The regression models constructed are used in the prediction phase to predict the carcass grading information.

Image Analysis. Traditionally on-line carcass grading has focused on the determination of the fat thickness. Fisher (Fisher, 1992) described a method for estimating the meat percentage from fat thickness measured on different positions of the carcass. The single fat thickness measured over the mid-dorsal line in the loin correlated most with the meat percentage. This observation has formed the basis for the feature extraction in the Autofom ultrasound system. Ultrasound images represent a profile of the fat layers and the experiences from the single position results reported by Fisher, are extended to multipoint representations of the fat thickness. The fat layers are referenced to the point with minimum fat thickness, namely the C-point.

Several algorithms for extracting the image information have been developed and implemented. The general form of the algorithms are briefly introduced in the following. First step in the image analysis is removal of noise; this can e.g. be accomplished by horizontal averaging filtering (Russ 1992). This processing step emphasizes the horizontal profiles and reduces the scattering and double reflections. Next step in the image analysis algorithm is detection of the transducer image containing the C-point, named the center image. This step is important to detect the orientation of the carcass in the transducer frame. Apart from containing the minimum fat thickness the center image is characterized by having a dark region in the center of the meat. Then follows extraction of the fat profile information in the center slice and the two neighbour transducer images. The image processing is only applied to these transducer images to reduce the processing time. Third step is detection of the intersection between the meat and the ribs. The minimum depth occurrence of the ribs is also considered a characteristic point labeled the D-point. Two more characteristic points are extracted, namely the A-point and B-point. The B-point is defined by the top of the fat profile in the loin before the ham and the A-point is defined by the first minimum of the fat profile following the B-point. The A, B, C and D points are detected with several different algorithms. In total 127 features describing the position (both the length and the depth) of the A-, B-, C- and D-points are extracted from the transducer images. These features are used in a multivariate regression analysis to predict the grading information (e.g. the meat percentage).

Multivariate Regression Analysis. The image features are used in a Partial Least Squares (PLS) (Bro 1995) multivariate regression model. The 127 image features are inserted as columns of a matrix denoted ***X***. The rows of ***X*** contains the different samples (i.e. the carcasses). For all samples, also a set of reference measurements (e.g. meat percentage) is contained in a matrix ***Y***. The product ***X*** is decomposed into a set of common orthogonal loadings (also known as latent variables) by maximizing the covariance between ***X*** and ***Y*** (Höskuldsson 1988). Thereby, the most informative data with respect to the reference information is used. The projection of the data onto the latent variables result in a more robust and less noisy representation of the measurements due to orthogonality of the loadings (Esbensen 1994). The dimension in the decomposed data set are formed by the loadings, which are common for all samples. The samples are separated by their score values, which are the multiplicative amount of the loadings. The regression coefficients are found on the score values in a least squares sense after the decomposition. Figure 5 illustrate the process of decomposition to the principal components. Three virtual fat profiles are shown to the left (can be interpreted as a subset of the 127 features). The two loadings describe the common characteristics in the structure of the three profiles. The three profiles are separated by the two score values (the factors multiplied to the loadings). What remains are only the residual, which are discarded. The regression modeling is performed on the score values as discussed above. An advantage of the PLS approach relative to e.g. a neural network calibration is that a better validation can be made on the data (e.g. estimation of future predictive performance with cross validation). Furthermore, a lower number of samples is usually required for a robust regression calibration compared to neural networks. The latter argument can be important when the grading information to be predicted is "expensive" dissection data as in the case in the case of the calibration of the Autofom.

The reader is referred to (Esbensen 1994, and Martens and Naes 1993) for a more thorough discussion of the PLS algorithm. When using the regression model on-line, the loading and the regression coefficients are used to first transform the feature vector into scores and perform the prediction with the regression coefficients. PLS regression models were constructed with program suite Unscrambler 6.1 (CAMO, Trondheim, Norway).

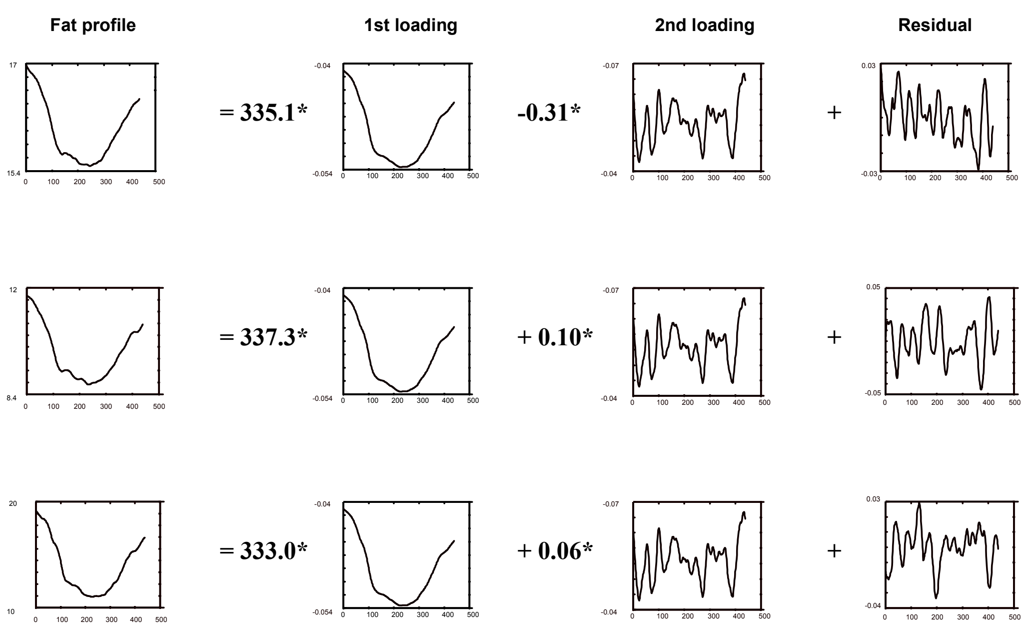

Figure 5. In PLS the data (here illustrated by a set of fat profiles) is decomposed to the loadings which are orthogonal and common for all the samples. What remains are the residual describing the remaining noise in the data.

EXPERIMENTAL CONDITIONS

The Autofom ultrasound system has been extensively tested at major slaughter lines in Denmark, Germany and US. The tests have concentrated on fire types of reference information: 1) fat and meat thickness measured with a manual ultrasound system, 2) total meat percentage measured with dissection, 3) total meat contents and 4) mass of primal cuts measured with dissection. In all tests, the Autofom has been used at regular on-line speeds ranging from 300 to 1,150 carcasses/h.

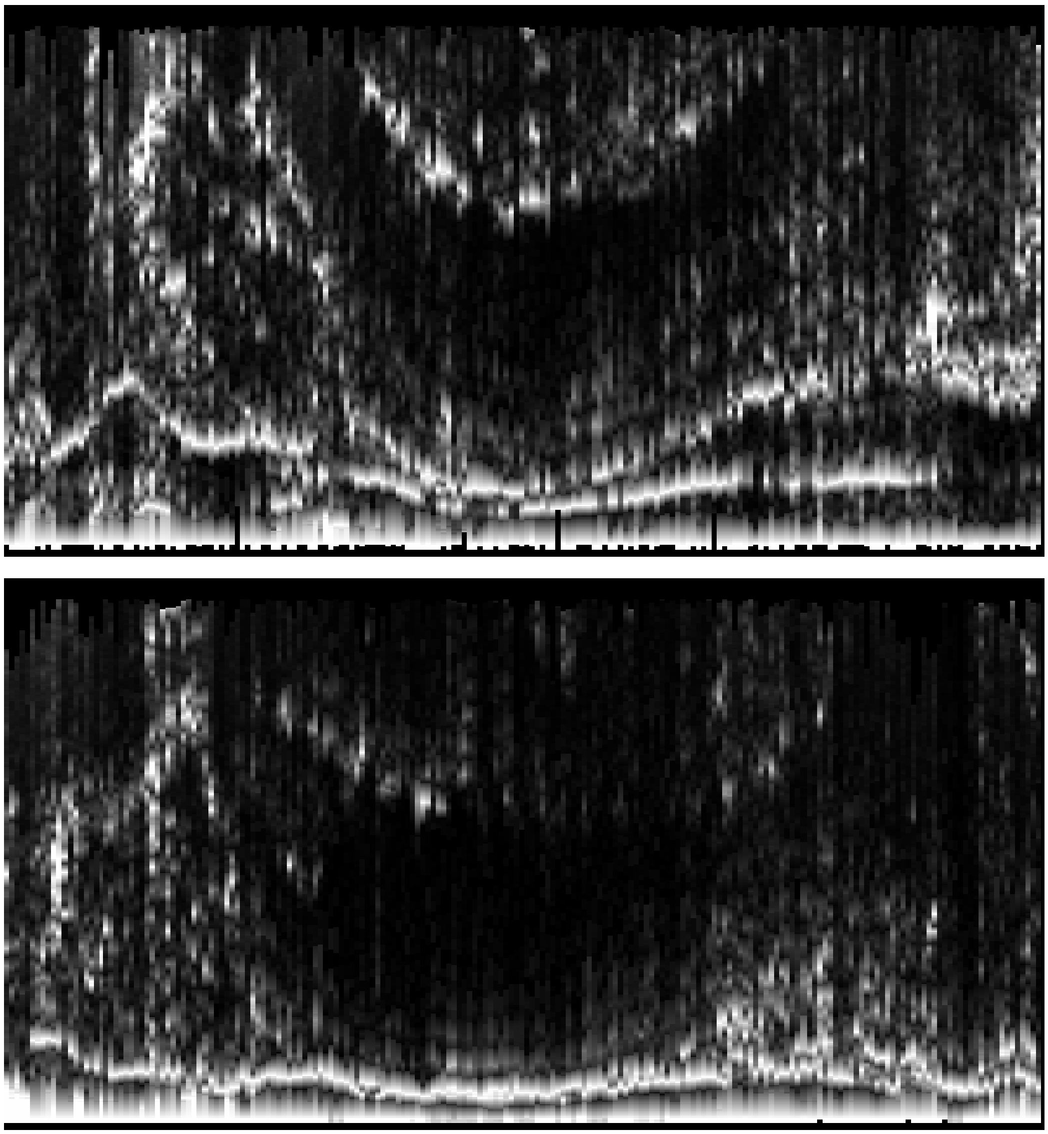

Figure 6. Ultrasound transducer images of top: a fat pig carcass (meat percentage of 57%) and bottom: a lean pig carcass (meat percentage of 64%). The left part of the images shows the ham, the middle part of the images show the loin and the right part of the images show the shoulder. Note the difference in the fat thickness over the loin between the two carcasses. The ultrasound images are rescaled horizontally with a factor of 4 to improve the interpretation.

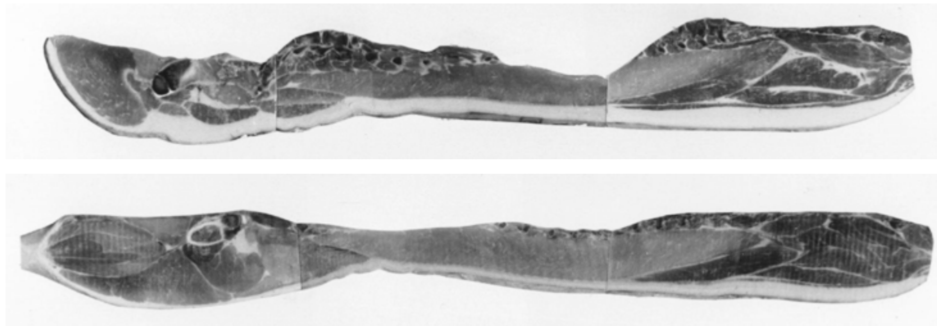

Figure 7. Photographs of the same two animals shown in figure 6. The animals are sliced in the length direction.

RESULTS

ULTRASOUND IMAGES

A transducer image describe the length profile of the animal. Figure 6 shows two examples of center transducer images of a fat (Figure 6 top) and a lean animal (Figure 6 bottom). The left part of the images shows the ham, the center part of the images shows the loin and the right part of the images shows the shoulder. The bottom part of the images shows the skin where the ultrasound transducers are positioned. The top part of the images shows a depth of approximately 10 cm. Note the clear subcutaneous fat profile in the lower part of the image. Also the ribs are visible as small white spots in the upper middle part of the ultrasound images.

Figure 7 shows photographs of the same two animals measured with ultrasound and shown in Figure 6. The carcasses are sliced in the length direction. The slicing is performed 24 h post mortem at approximately the same position as the on-line ultrasound measurements shown in Figure 6 have been made.

The lean animal in Figure 6 and 7 has a total meat percentage of 64.2 % and the fat carcass has a meat percentage of 57.5 %. A clear difference is observed both in the ultrasound and in the photographic representation between the two animals.

A perfect superimposition of the ultrasound images and the photographs cannot be expected. This is mainly due to biological changes and difference in the slaughtering process at the time the two data acquisitions have been performed (45 minutes post mortem for the ultrasound representation and 24 hours for the photographic representation). However, the photographic representation of the animal is of great value when interpreting the more noisy appearance in the ultrasound images.

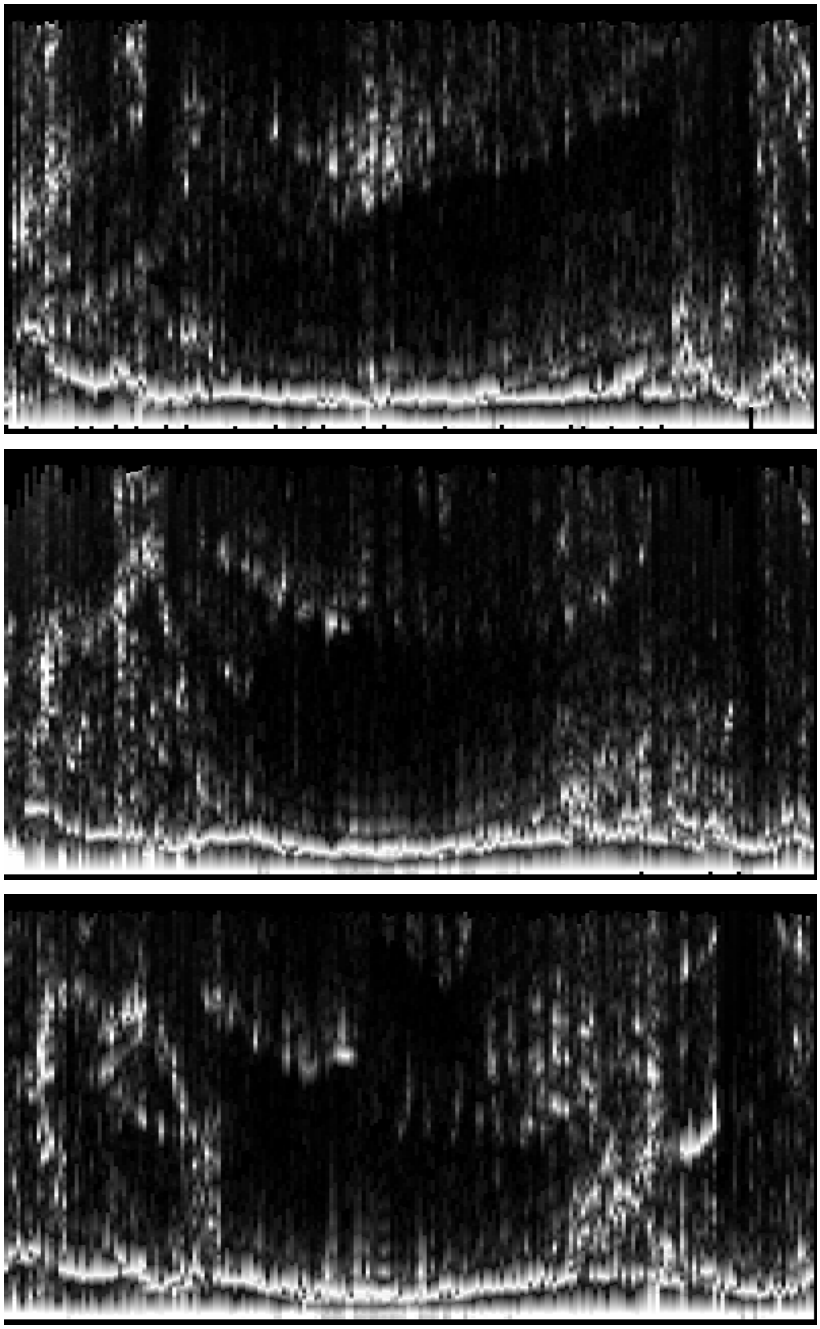

Figure 8. Three neighbour transducer images. The middle is the center transducer image (note the minimum fat thickness).

The center transducer image presents the image with the minimum fat profile. An example of the center transducer image extracted by the image analysis algorithm is shown in Figure 8 (middle). The top and the bottom image in Figure 8 represent the neighboring transducer images relative to the center image. The feature extraction algorithm is applied to all three images for each on-line evaluation.

The noise levels in the images are high. Both double reflections and scatter noise are apparent. The double reflections are especially apparent following the subcutaneous fat layers in the loin region. The scatter noise does not appear to be of a significant level in the loin. In the ham and the shoulder region the scatter noise level is considerably higher. Figure 9 shows a region from a center image before and after the noise reduction in the image analysis algorithm. The appearance of the fat profile is improved and the noise level is clearly reduced. Since the major data analysis is performed on the loin part no further attempts to reduce the scatter noise is needed. The features for the center image contain information about the fat layer, the depth of the meat rib intersections, the A and the B points. For the two carcasses (represented ultrasonically and photographically in Figure 6 and 7) the average fat thickness in the loin region is measured to 15.41 and 8.78 mm for the fat and for the lean carcass respectively. The average depth of the meat rib intersection is measured to 75.52 and 64.94 mm for the fat and for the lean carcass respectively.

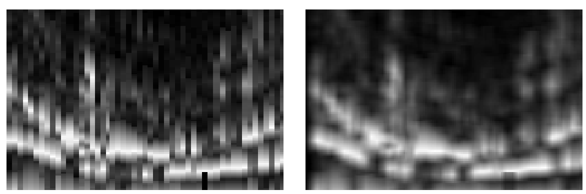

Figure 9. A sub region of an ultrasound image after the noise reduction step in the image analysis. Note the clear reduction of the noise level, and the improved appearance of the fat profiles.

TRIAL 1: FAT AND MEAT THICKNESS

450 carcasses were measured on-line with the Autofom system with a processing speed of 650 carcasses/h. The fat and the meat thickness at the $3^{rd}/4^{th}$ last lumber vertebra of the animal were measured manually with an Aloka SSD 256 scanner (Aloka, Simonsen & Weel, Taastrup, Denmark). The manual reading was performed accurately and 10-15 minutes were spend on each measurement by a meat specialist from the German Meat Research Institute, Kulmbach, Germany. A statistic evaluation of the manual ultrasound measures is given in Table 2. The fat thickness and the meat rib thickness for the 450 carcasses averages to 15.50 mm and 61.33 mm respectively.

For the fat measures, the correlation between the predicted and the measured thickness equals $R = 0.94$ ($R^2 = 0.88$) with a residual standard deviation of RSD = 1.24 mm. For the meat thickness, the equivalent features equals $R = 0.88$ ($R^2 = 0.77$) and RSD = 2.90 mm. The error is notably higher for the meat thickness than the fat measures. This is due to difficult determination of the D-point features, which are extracted from the ribs in the ultrasound images. The ribs occur as small white dots in the image and are less well defined than the fat profile. Generally the fat profile features are more robust in the data regression. The previous approval trial for classification equipment in Germany was prediction of the reference information used in this trial. The approval limit for new grading equipment demanded maximum standard deviations of 1.4 mm and 3.0 mm for the fat and the meat thickness respectively. Both these requirements are fulfilled with the Autofom ultrasound predictions.

Table 2. Statistical evaluation of the reference information from the three trials

	Unit	N	μ	σ	Min	max
Fat Thickness	mm	450	15.46	4.22	7.95	36.47
Meat Thickness	mm	450	61.33	6.34	43.86	78.54
Meat Percentage (Danish Test)	%	344	59.38	3.60	48.94	67.31
Meat Percentage (German Test)	%	148	57.52	3.95	47.34	66.64
Meat Percentage (US Test)	%	120	55.99	2.78	48.17	62.49
Meat Contents Ham	kg	148	12.06	1.43	8.61	15.13
Meat Contents Loin	kg	148	5.50	0.71	4.03	7.41
Meat Contents Shoulder	kg	148	5.42	0.65	4.19	6.74

TRIAL 2: MEAT PERCENTAGE

Four different abattoirs (Germany, US and two in Denmark) were used for the trial. In the four tests respectively 148, 120, 150 and 194 carcasses were measured on-line with the Autofom. The four line speeds were respectively 650, 1150, 450 and 300 carcasses/h according to the normal grading speed at the respective lines. In the Danish test the carcasses were also measured with the Danish Classification Center (see Busk and Olesen 1996 and Klinth-Jensen 1991). In the German test, the carcasses were also measured with a manual ruler measured at two positions (ZP), the Fat-O-Meater (FOM) and the Aloka SSD 256 (see Brandscheid, 1997b).

The grading information obtained in the tests differs depending on the cutting procedures used in the respective plants. In the Danish and the German test the total meat percentage was measured by the EU regulation method (Walstra, 1995). In US the primal cut percentage was measured by the standard procedure used at the slaughterhouse.

Statistic measures of the meat percentages measured with the cutting procedures in the three different trials are given in Table 2. The statistics indicate a low variance in the US primal meat percentage data. This may cause a less robust prediction calibration.

The result of the Autofom predictions is given in Table 3. For both European tests the prediction results of the total meat percentage are well below the European Commission limit of approval of 2.5 %

Table 3 Results of the predictions in the meat percentage trial

	RSD (%)	r^2
Autofom Predictions[1]	1.84	0.74
KC Predictions [1]	1.70	-
Autofom Predictions[2]	1.58	0.85
ZP Predictions[2]	2.44	0.62
FOM Predictions[2]	2.01	0.74
Aloka Predictions[2]	1.84	0.77
Autofom Predictions[3]	1.70	0.77
FOM Predictions[3]	2.35	0.65

1 Prediction of the total meat percentage in the Danish test

2 Prediction of the total meat percentage in the German test

3 Prediction of the primal cut percentage in the US test

For the European tests, the prediction results of the total meat percentage are well below the European Commission limit of approval of 2.5 %. The prediction of the primal cut percentage in the US test result in an RSD of 1.70 %. The Autofom predictions are 38 % better than the results obtained with the FOM. The error level is similar to that obtained in the European tests for the total meat percentage despite the difference in the cutting procedure and the lower variance seen in the data set from Table 2. The improvement relative to the FOM is believed to be due to the objectiveness and the increased number of measured positions.

A comparison of the results of the Autofom predictions with those obtained with the Danish Classification Centre (KC) in the Danish test reveal, a lower prediction error for KC. This indicates a superior grading performance for KC. However, part of the difference in the grading performance may be due to more refined and robust regression models for the KC, which have been used in Danish pork grading since 1986. Furthermore, the insertion probe measurements by KC in the shoulder region of the carcasses may be more informative than the ultrasound measurements in this region, where a less stable contact can be observed for the Autofom. However, the Danish test was performed with an older data analysis version in the Autofom system. Data processing improvements introduced after the Danish trial were used in the German and the US test.

A comparison between the four instrumentations in the German test reveals the lowest prediction error for the Autofom predictions. The FOM presented a RSD of 2.01 %, the ZP had an RSD of 2.44 % and the Aloka 256 had an RSD of 1.84 %. The lower prediction performance was expected for the FOM and the ZP measurements, which are manual measurements made on one (FOM) or two (ZP) positions only. The fact that also the Aloka provides inferior performance is interesting. The Aloka measurements are very thorough manual tests (10-15 minutes pr. carcass) and reproduction of these measurements were the previous approval condition in Germany as mentioned in Trial 1. The Aloka approach can be regarded as the upper limit achievable with a manual serviced ultrasound equipment and still the performance is significantly poorer ($P<0.07$ determined with an f-test) than the Autofom equipment in the German test.

In general the Autofom and the KC appear to present the best grading performance with respect to low prediction errors of the meat percentage in the study presented here. This demonstrates the advantage of increasing the number of measurement positions on the carcasses (Kempster *et. al.* 1982). Furthermore, the fact that these two instrumentations are fully automatic and thereby objective is advantageous when considering total grading costs.

TRIAL 3: PRIMAL CUTS

In the German test mentioned in Trial 2 the carcasses were dissected into the meat primals: the ham, the loin and the shoulder. The dissections followed the local cutting regulations at the slaughterhouse. A statistic overview of the reference information for the meat primals is given in Table 2.

Total meat content is as opposed to meat percentage information dependent on the total carcass weight. Therefore the hot carcass weight is included as an input along with the ultrasound image features to the regression analysis. The result of the test is presented in Table 4. For comparison, also the prediction performance of the FOM with the carcass weight information is presented. For all the major primals the RSD of the predictions with the FOM are significantly higher than the corresponding Autofom predictions ($P<0.01$, $P<0.03$ and $P<0.01$ for the ham, the loin and the shoulder predictions respectively determined with an f-test). For the Autofom the error ranged from .15 to .31 kg and for the FOM the error ranged from .18 to .46 kg. For both systems the prediction of the ham mass presents the least accurate performance.

Table 4 Residual standard deviations (kg) of the Autofom and FOM predictions of the meat contents in the primal cuts

	Autofom	FOM
Ham	0.31	0.46
Loin	0.15	0.18
Shoulder	0.15	0.20

The results of the Autofom predictions imply that there is an advantage in increasing the number of measurement positions on the carcass in a grading situation. With the number of measured positions increased from 1 to 3,200 the RSD of the predictions are up to 33 % lower. Since the information still is obtained at on-line speeds, this suggest the information of the primal cuts being combined with the meat percentage in both carcass grading and internal sorting on the processing line.

IMPLICATIONS

The Autofom has the potential to meet the requirement of high speed of pork grading. The grading performance obtained at fast line speeds is comparable and in most cases better than existing grading equipment. Features as the objectiveness and the total carcass scanning are furthermore strong features of the system. Future application of more detailed and qualitative carcass composition description (as e.g. primal cuts as described here) can enable a more optimal sorting based on measurements obtained early in the slaughtering process.

LITERATURE CITED

Aridge, J. T., B. W. Brorson, L. D. Whipker, J. C. Forrest, C. H. Kuei and A. P. Schinkel. 1992. Evaluation of alternative techniques to determine pork carcass value. J. Anim. Sci. 70:18.

Bowman, G.H.. J.A.Whatley Jr. and L.E.Walters. 1962. Separation and measuring errors in swine carcasses. J. Anim. Sci. 21: 950-954

Brandscheid, W., A. Dobrowolski and R. Höreth. 1997a. Neue Schätzformel und ein Neues Gerät (German). Top Agrar. March. 3:8.

Brandscheid, W., A. Dobrowolski and R. Höreth. 1997b. Bestimmung der Handelklassen und des Handelswertes von Schweinhälften mit dem Gerät Autofom (German). Oral Presentation. Contact Prof. Brandscheid, Bundesanstalt für Fleisch Forschung, Kulmbach, Germany.

Bro, R. 1995. Multivariabel kalibrering (in Danish). p 53. DSR Tryk, Copenhagen, Denmark.

Brøndum, J. 1996. Grading moves to multipoint measurement. Pig International. August:10.

Busk H. and E. Olsen. 1996. Determination of percent meat in pig carcass with the autofom equipment. *p 9*. 47th Ann. Meeting of the European Ass. for Animal Production, Lillehammer, Norway. August 25-29.

Esbensen, K, S. Schönkopf and T. Midtgaard. 1994. Multivariate Data Analysis in Practice. *p 11-20,101-132.* Wennbergs Trykkeri, Trondheim, Norway. ISBN 82-993330-0-8.

Fisher, A. V. 1992. New approaches to measuring fat in carcasses. In: J.D. Wood and A.V. Fisher (Ed.) Reducing Fat in Meat Animals. p 270. Elsevier.

Gresham, J. D., S. R. McPeake, J.K. Bernhard and H.H. Henderson. 1992. Commercial adaption of ultrasonography to predict pork carcass composition from live animal and carcass measurements. J. Anim. Sci. 70:631.

Höskuldsson, A., 1988, PLS Regression Methods, J. of Chemometrics, 2, p 211-228.

Jacobson, B., 1987, Medicin och Teknik (In Swedish), p 428, Studentlitteratur, Sweden. ISBN 91-7810-965-5.

Klinth-Jensen, W. 1991. Optical probes: single probes and classification system. Proc. of Th. Symp. Elec. Eval. of Meat in Support of Value based Marketing. Purdue Uni. West Lafayette, In. p 11-22.

Lasley, E. L. and E. A. Kline. 1957. Splitting and cutting errors in swine carcass evaluation. J. Anim. Sci. 16: 485-489

Liu, Y. and J. R. Stouffer. 1995. pork carcass evaluation with an automated and computerized ultrasonic system. J. Animal Science. 73:29.

Kempster, A.J., Cuthbertson, and Harrington, G., Carcase Evaluation in Livestock Breeding, Production and Marketing, Grenada Publishing ltd., London. ISBN 0-246-11509-2

Martens H. and T. Naes. 1993. Multivariate Calibration. p 85-166. 2nd edition, John Wiley and Sons Ltd. ISBN 0-471-90979-3.

Russ, J. C. 1992. The Image Processing Handbook. p 55. CRC Press. ISBN 0-8493-4233-3.

Swatland, H.. 1995. On-line Evaluation of Meat. p 1-22. Technomic, ISBN 1-56676-3339.

Walstra P. and G. S. M. Merkus. 1995. procedure for assessment of the lean meat percentage as a consequence of the new EU reference dissection method in pig carcass classification. p22. DLO Research Inst. for Animal Science and Health, ID-DLO Research Branch Zeist, P.O. Box 501, 3700 Zeist, The Netherland.