in the os calcis with selection of an optimal ROI of any size and shape and should overcome the problem of transducer positioning.

5.10 COMPUTER INTERPRETATION OF ULTRASOUND IMAGES TO ESTIMATE INTRAMUSCULAR FAT IN LIVE CATTLE, John R. Brethour. Kansas State University, Fort Hays Branch Experiment Station, Hays, KS 67601.

Intramuscular fat (marbling) is an important indicator of beef palatability and is the primary element in the USDA grading procedure. This trait cannot be visually estimated in live cattle but is related to the amount of speckle in ultrasound images captured from the location where carcasses are evaluated (a tomogram of the longissimus between the 12th and 13th rib). Automating image interpretation would overcome the difficulty in standardizing visual image classification and enable upstream applications that model the development of this important trait. Images were used from 53 cattle in the training set and from 108 cattle in the validation set. Over 500 texture statistics that parameterized the echograms (including variations in direction, resolution, and step size) were screened to identify three candidates (Markovian homogeneity - step size = one; third quadrant emphasis from the bit-4, normalized run length/gray level matrix; and local standard deviation in a one-dimensional 12-pixel primitive) for intensive analysis. Neural network processing of those texture statistics resulted in marbling estimates that differed from corresponding USDA carcass marbling scores by an average of 0.42 marbling score units. That was more accurate ($p < .001$) than using the same features in a multiple regression model. The differences between the ultrasonic live animal estimates and carcass marbling were not much greater than the human error in assigning carcass marbling scores. Subjecting the results to receiver operating characteristic analysis indicated that accuracies in grade classification were comparable to clinical, diagnostic imaging evaluations.

6. Imaging I

6.1 EFFICIENT GENERATION OF LIMITED DIFFRACTION BEAMS BY HEXAGONAL ARRAYS, M. Fatemi and S. Shirani, Biomedical Engineering Department, Amirkabir University, Hafez St. No. 424, Tehran, Iran.

Limited diffraction beams are potentially useful in ultrasonic imaging applications because of their large depth of field. Annular arrays may be used to produce diffraction-limited beams. This is motivated primarily by the fact that the these beams often have circular symmetry. Rapid beam steering, required for real time imaging can be achieved best by employing electronic scanning systems. Unfortunately, beams generated by annular arrays cannot be steered electronically. As an alternative, two dimensional (2-D) array transducers have been suggested recently for generation and electronic steering of limited diffraction beams. However, ordinary 2-D arrays with rectangular element arrangements require a large number of elements (about 1700) and complex electronics to produce large number of driving functions. In this paper, we propose a 2-D array with a hexagonal element arrangement for this purpose. Taking advantage of circular symmetry of the beam, it is shown that this array can produce a beam equivalent to that of an ordinary 2-D array using 13.4% less elements. In addition to the saving on the number of elements, the hexagonal array offers a great saving on the number of independent driving functions needed for generation of the beam. Generation of limited diffraction Bessel beam and the X waves, using either a rectangular or a hexagonal array transducer, are studied by computer simulations. In this study, an aperture of 25 mm diameter at 3.5 MHz center frequency is considered. Fields of a 41x41 elements rectangular array and an equivalent 35x41 hexagonal array are calculated and shown to be of the same precision. Furthermore, it is shown that the rectangular array requires 147 independent driving functions, while the hexagonal array requires only 93, reducing the complexity of the electronic waveform generation system by 36%. Savings offered by the hexagonal arrangement are more appreciated in the case of the X waves, because they require complex driving functions that are totally different in shape for elements located at different radial distances. It is concluded that the hexagonal elements arrangement is superior to the rectangular arrangement for generation and linear scanning of limited diffraction beams.

6.2 MODELING AND EXPERIMENT OF DOPPLER SHIFT AND ITS SPECTRAL BROADENING FOR A BESSEL BEAM, Jian-yu Lu, Xiao-Liang Xu, Hehong Zou and J.F. Greenleaf,

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Limited diffraction beams have a large depth of field. These beams could have applications in medical imaging, tissue characterization and nondestructive evaluation of materials.

In this report, we study the application of limited diffraction beams, specifically the J_0 Bessel beam, on velocity measurement using the Doppler shift and its spectral broadening. We have modeled a point scatterer and a line of random scatterers traveling through the central region of the Bessel beam at several angles and derived formulas to calculate the Doppler shift and its spectral broadening. Computer simulations correctly predict the Doppler shift and the bandwidth. This result is different from a conventional focused beam that produces a triangular Doppler spectrum shape when scatterers move at a single velocity [1]. The shoulders in the Bessel Doppler spectrum might increase the accuracy of the measurement of the bandwidth of the spectrum, which is important for the estimation of the angle between the velocity and the axis of the beam.

Our experiment consisted of a thin, smooth nylon fishing line glued with an epoxy spot that was used as a point scatterer. A cotton sewing string was used as a line of random scatterers. The strings were transported at a velocity of about 0.3 m/s and passed through the center of the Bessel beam. Data from the point scatterer were collected at an angle of 45°, and the date from the line of random scatterers were collected at four angles: 45°, 70°, 80° and 90°. About 10 spectra for the point scatterer and 40 spectra for the line of random scatterers were averaged. The time window (weighted with a Blackman window) for calculating the spectra was 66.67 ms so that the scatterers traveled 20 mm at the speed of 0.3 m/s. Both 20 and 40 μs tonebursts (2.5 MHz central frequency) weighted with the Blackman window at their ends were used to excite a 50-mm diameter, 10-element annular array transducer to produce the Bessel beam. The experiment results agree with the predictions from the computer simulations. The peak of the Bessel Doppler spectra predicted the speed of the string to within about 1%. The shoulders at 70° predicted the angle to within 10%.

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[1] Newhouse, V.L., Censor,D., Vontz, T., Cisneros, J.A. and Goldberg, B.B. Ultrasound Doppler probing of flows transverse with respect to beam axis, *IEEE Trans. Biomed. Eng. BME-30*, 789-99 (1987).

6.3 HIGH-RESOLUTION ULTRASONIC IMAGING WITH CODED-EXCITATION SYSTEMS,

Jain Shen and E.S. Ebbini, Department of Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, MI 48109.

A new approach for ultrasonic imaging using coded-excitation array systems is presented. The approach is based on a spatio-temporal discretization of the imaging equation, assuming scatterers on a uniform grid in the region of interest (ROI). The ROI is discretized as N_r range points along the NB image lines in a sector format. The spatio-temporal discretization results in an imaging equation of the form: $\mathbf{f} = \mathbf{G}\mathbf{s} + \mathbf{n}$, where $\mathbf{f} = [f_1, f_2 \ldots, f_{N_s}]^t$ is the received samples complex data vector, $\mathbf{s} = [s_1, s_2, \ldots, s_{N_g}]^t$ is the complex scatterer strength vector ($N_g = N_r \times NB$), $\mathbf{n}$ is a noise vector, and $\mathbf{G} = [G_1\ G_2 \ldots G_{NB}]$ is a spatio-temporal impulse response matrix with G_i representing the impulse response of the system along the ith image line. A minimum-norm least-square error estimate of the scatterer distribution in ROI is obtained through the pseudoinverse of $\mathbf{G}$. Under some simplifying (but realistic) assumptions, the pseudoinverse can be implemented as a set of transversal filters, where each filter reconstructs the scatterer distribution along one image line. We will show that the resulting filters decorrelate echoes from different directions and perform Wiener inverse filtering along one direction. An important advantage of the proposed system is that its resolution is not diffraction limited as is the case with conventional imaging arrays. We show one configuration which involves the use of a 15-element transmitting array driven by 15 127 chip pesudorandom codes and a conventional 128-element receiving array. Experimental results with this configuration supported the theoretical and simulation results and have shown that we can routinely resolve 7 different point targets distributed laterally within one beamwidth of the conventional array. A derivation of the pseudoinverse operator and the filter bank implementation will be given followed by representative experimental results of lateral and longitudinal resolution enhancement over conventional pulse echo systems. Applications of the new algorithm in 3D imaging will also be discussed.

PROGRAM AND ABSTRACTS

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