Most of present ultrasonic techniques to clinically assess bone properties are implemented by measuring the speed-of-sound (SOS) or broadband ultrasound attenuation (BUA) in the calcaneus using two aligned transducers. These modalities allow measurements of bone tissues only at certain locations due to the arrangement of transducers. The accuracy of these techniques moreover is affected by many factors including geometry of the bone and the thickness of soft tissues. To alleviate these complications, we extensively applied ultrasonic backscattered signals to assess bone tissues using a 1 MHz single element transducer. The acquired backscattered signals were digitalized at a 20 MHz sampling frequency and 12-bits resolution. The m parameter of Nakagami distribution, a more sensitive and feasible parameter to quantify bone properties than that of backscattered strengths validated from results of both computer simulation and previous measurements, was on-line calculated from digital backscattered signals. The clinical assessment of bone tissues was performed on 41 osteoporotic patients of whom examinations were carried out by applying both ultrasound, was implemented in both the tibia and the calcaneus, and dual-energy X-ray absorptiometry (DEXA), was to measure bone mineral density (BMD) in the hip. Those m parameters measured from both the cancellous bone of the tibia and the calcaneus were normalized by that from the central portion of the tibia. Fairly linear relationships were found between the BMD of the hip and those normalized m parameters acquired from the cancellous bone of the tibia (correlation coefficient, $r = 0.61$) and that from the calcaneus ($r = 0.63$). It remains not fully clear about whether current ultrasonic backscattering technique or DEXA has a better accuracy to assess the bone tissues. However, ultrasonic backscattering technique using one transducer has a further potential to quantitatively assess the bone tissues for clinically diagnosis due to it is free of radiation and that BMD measured from DEXA naturally has lost an information of bone properties in the thickness direction.

This work was supported by National Science Council, Taiwan, R.O.C. of the grants: NSC 90-2213-E-033-022 and NSC 91-2320-B-033-001

Session: P2C
MEDICAL IMAGE PROCESSING
Chair: J. Hossack
University of Virginia

P2C-1

PERFORMANCE EVALUATION OF COMBINED SPATIAL COMPOUNDING/ADAPTIVE IMAGING: SIMULATION, PHANTOM AND CLINICAL TRIALS
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Spatial compounding reduces speckle and increases image contrast by incoherently averaging images acquired at different viewing angles. Adaptive imaging improves contrast and resolution by compensating for tissue induced phase errors. Aberrator strength and spatial frequency content markedly impact the desirable operating characteristics and performance of these methods for improving image quality. We present simulation, phantom and clinical experiments of spatial compounding, adaptive imaging, and a combination of these two methods in contrast and resolution tasks. We describe the effects of aberration strength and spatial frequency content on these methods for variable aperture size and overlap employed in spatial compounding. Experiments were performed with a custom 8x96, 1.75D probe (Tetrad Corp.) interfaced with a Siemens Antares Scanner which can acquire individual rf channel data. For simulation and phantom measurements, electronic aberrations with strengths of 0 to 46 ns RMS and correlation lengths of 2.5 to 6 mm were used to image a spherical lesion phantom with 2 mm cysts. As aberration strength and spatial frequency content increase, the ability of phase correction algorithms to estimate time delay errors diminishes, due to the decreasing speckle correlation. Under spatial compounding, the number of independent images acquired increases an average of 57% for strong aberrations. Applying adaptive imaging before compounding reduces this to 29%. For weak aberrations, spatial compounding yields higher CNR regardless of imaging parameters. At high aberration strength and low spatial frequency content, spatial compounding can yield significant (20-50%) improvements in CNR. For high aberration strength and spatial frequency content, adaptive imaging dominates in performance. CNR performance for both of these imaging techniques used concurrently is better than for either method used alone. We present results of these methods on clinical thyroid data in 7 patients and discuss their performance under the measured aberration characteristics of these examples.

NIH grant RO1-CA43334

P2C-2

MOUSE MYOCARDIUM SEGMENTATION FROM ULTRASOUND IMAGE USING A SNAKE ALGORITHM

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The mouse heart is often used as an animal model for human cardiovascular disease. In particular, there is an interest in very quickly assessing left ventricular volume, ejection fraction and mass. These metrics require fast, automated detection of the relevant boundaries in relatively noisy mouse heart images. In this paper, we address automatically delineating the inner and outer boundaries of the mouse myocardium from ultrasound images using active contours or snakes. A snake is a closed curve that can move from an initial contour to gradually conform to an object boundary (if the initial contour is close enough to the target boundary). There exists no general method for initializing a snake. In practice, manual initialization is commonly used. In this paper, we present
an automatic initialization method by exploiting visual features in ultrasound
images of a mouse heart. We used two snakes to detect the inner and outer
contours of the myocardium, respectively. The inner snake initialization is based
on the observation that the heart chamber is the largest dark area in the heart
image (short axis view of left ventricle). The image is firstly filtered using a
Gaussian filter. The filtered image is then thresholded to obtain a binary im-
age of all the dark regions. Subsequently, connected component labeling is
employed. Finally, the largest object is identified as the left ventricular cham-
ber and its contour serves as the initial snake for detecting the inner contour
of the myocardium. Once the inner boundary is obtained, the outer snake is
initialized to find the outer boundary of the myocardium. The outer snake is
initialized as a slightly elliptically distorted circle. We do this because we know
from experience that the outer boundary shape of the myocardium is relatively
invariant across individuals and hence we can detect realistic estimates of the
outer boundary even in the face of poor image quality. The outer snake has been
observed to quickly converge to the ‘true’ boundary. The algorithm has been
tested on twenty frames of a mouse heart ultrasound video sequence. Visually,
both inner and outer initial snakes converge satisfactorily to the boundaries of
the myocardium as discerned by expert human visual assessment.

P2C-3

OPTIMUM FRAME INTERVAL FOR ULTRASOUND
IMAGE MOTION ESTIMATION
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Several clinical applications depend on frame-to-frame motion estimation of ul-
trasound images. Among these, an Extended Field of View image is an extended
panoramic image composited from a set of displaced and aligned images. There
is an expectation that reliable linear dimensions may be extracted from the re-
constructed image. Assuming that there is finite noise in the image frames and
that image speckle partially decorrelates between frames we hypothesized that
an optimal inter-frame interval must exist that provides the smallest relative
dimensional error over a set of accumulated motion estimates. In this context,
‘frame interval’ is defined as the physical spacing between image frames used
for motion estimation. (Alternate frame intervals are implemented by using
different subsets of acquired images for motion estimation.) Smaller frame in-
tervals suffer from smaller decorrelation induced alignment errors but present
greater potential for cumulative error due to the increased number of estimates
combined over any chosen dimensional interval. Larger intervals suffer greater
decorrelation, but fewer estimates are combined. We studied this tradeoff using
a combination of theoretical modeling, numerical simulation and experiments.
The theoretical component was based upon a new Cramér-Rao Lower Bound on
lateral displacement estimation. This bound includes image SNR, system PSF,
image displacement and correlation window size. A satisfactory match between
theory, simulation, and experimental results was obtained. Optimal intervals
were established but these are dependent on a large number of variables (e.g. center frequency, image SNR, aperture dimension in azimuth and elevation direction, and angle of actual transducer translation versus ideal (ie zero degrees with respect to the azimuthal-range plane). Some of these parameters (especially the angle of the transducer translation) are difficult to assess in practice. Nevertheless, it appears that in the majority of practical cases, it is advisable to use every available image frame rather than ‘skipping’ intermediate frames. We have achieved a dimensional accuracy of 5% in the reconstructed (lateral) dimension using experimental data for cases where the angle of transducer translation is 5 degrees or less.

The Whitaker Foundation, Siemens Medical Solutions

P2C-4

ADAPTIVE SPECLE REDUCTION PROCESS 
ENHANCING STRUCTURE AND TEXTURE OF B-MODE IMAGE

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It is well known that conventional B-mode images are formed with specles, whose typical patterns do not directly reflect the microscopic structures of tissues. Specle reduction approaches in medical B-mode imaging for easier interpretation of the macroscopic structures of tissues in the original image have been experiencing two major difficulties: 1) possible deterioration of spatial resolution and 2) sonographic experts’ preference for conventional images with the texture-like components formed with specles. A new adaptive image process is proposed to overcome these two difficulties at the same time. The process consists of three steps: 1) extraction of structural components from the image, 2) extraction of texture-like components, and 3) combination of these two components. The structural and texture-like components were extracted using an adaptive spatial low-pass filter and high-pass filter, respectively, in which the contribution of pixels with signal intensity greatly different from the central pixel was suppressed. The proposed process was installed to a high-resolution diagnostic scanner, EUB-8500, at 2-13 MHz and tested. Pixel intensities in the original diagnostic B-mode images were statistically analyzed first, and the parameters of the adaptive spatial low-pass and high-pass filters were optimized based on the statistical results. It was designed to process a frame within 15 ms so as to maintain the real-time capability of B-mode imaging. Comparison between the B-mode images before and after the proposed process showed significant enhancement of the structural components with the texture-like components maintained or even enhanced. The processed images with and without the adaptive control of the spatial low-pass and high-pass filters were also compared.
Comparison between with and without the adaptive control of the low-pass filter clearly showed that the speckle reduction maintaining spatial resolution was achieved due to the proposed adaptive control.

**P2C-5**

**SPATIAL ANISOTROPIC DIFFUSION AND LOCAL TIME CORRELATION APPLIED TO SEGMENTATION OF VESSELS IN ULTRASOUND IMAGE SEQUENCES**

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Segmentation of vessels on Intravascular UltraSound images is a determining factor for the diagnosis of pathologies like atherosclerotic plaque, and supplies complementary information for the study of endothelial wall diseases.

The diffraction speckle noise makes the segmentation of lumen a difficult task because of the similar echogenicity of blood and that of tissues or plaque, especially in the case of thrombus.

The interest of this study is to obtain (1) the spatial edge-sensitive detection of intraluminal contour, (2) an enhancing effect on the sides of the edges and (3) the preservation of the discontinuity of tissue characteristics of homogeneous regions using time and spatial information.

This can be performed with a 2D+t method based on a spatial, non-linear speckle reducing anisotropic diffusion, applied to a sequence of images weighted with a local time correlation.

The diffusion technique combines a normalized gradient magnitude operator and a normalized laplacian operator to act like an edge detector on a sliding window.

The Pearson normalized time-variance correlation is well adapted to ultrasound image sequence because it is not affected by the fluctuations of magnitude and offset between two successive images and provides a precise detection of artery edges.

The feasibility of enhancing the contrast of luminal edges in the parametric mapping is demonstrated comparing the image resulting from our method with the experimental reference image.

The sequence of frames is the output of an ultrasound catheter with a 30 MHz central frequency allowing the capture of 7 images of 256 scan-lines each for an investigation depth of 7 mm. In vitro experiments were conducted with a cryogel phantom mimicking artery perfused by a sodium chloride solution at a flow rate of 88 ml/min.

Results are obtained from a mask of 3x3 pixels used for the combined calculation of correlation and diffusion.

Processing efficiency is measured with Pratt figure of Merit. This gives a 0.84 coefficient against a value less than 0.76 for the simple correlation processing.
TOMOGRAPHIC RECONSTRUCTION OF SOUND VELOCITY DISTRIBUTION IN THE BREAST USING LINEAR ARRAYS
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Detection of breast cancer using B-mode ultrasound is of clinical importance. Its performance, however, is often limited by the poor contrast resolution. Contrast mechanisms based on alternative tissue characteristics, such as the sound velocity, may offer additional diagnostic information. An approach based on limited angle transmission tomography for reconstruction of sound velocity distribution in the breast is proposed in this paper. The imaging setup is similar to that of X-ray mammography. With this setup, the time-of-flight data is acquired by a linear array positioned at the top of the compressed breast and a metal plate is placed at the bottom as a reflector. Such a setup can be easily integrated with a B-mode system so that the acoustic data for both the B-mode image and the sound velocity reconstruction can be simultaneously acquired. Due to the limited projection angles, however, the acquired data is incomplete and this results in inaccurate sound velocity estimation. In order to improve the estimation accuracy, a new reconstruction algorithm based on convex programming formulation is developed. This algorithm incorporates segmentation information from the corresponding B-mode image in order to impose certain constraints during estimation. Extensive simulations are performed on different tissues with different geometries and acoustic parameters, including glandular tissue, fat and tumor (sound velocity is at 1521, 1471, 1549 m/s, respectively). The B-mode images are simulated using a k-space method that accounts for diffraction, refraction, scattering and attenuation. The time-of-flight data is generated using the series solution to the scattering equation of a plane wave incident on a fluid cylinder. Simulation results based on a 5 MHz linear array show that the sound velocity error generally ranges from 1-3 m/s with a maximum at 5.8 m/s. The radius of the object under investigation is from 2-6 mm and all the objects can be successfully detected. Thus, the proposed approach has good accuracy and the feasibility of the limited angle transmission tomography using linear arrays is numerically proven. The approach can also complement conventional B-mode imaging to further enhance breast cancer detection.