eye. We estimate the time to 80% intensity for the in vivo data and demonstrate that this time ranges from 0.8 to 6.7 s. ROIs from within the iris include a range of reperfusion times expected for arterioles and capillaries. ROIs from the ciliary processes yielded slower perfusion as expected from vascular casts of the microcirculation in this region. Potential applications of this system include high-resolution perfusion assessment in small animals.

We acknowledge the NIH (CA 76062) for their support.

Session: 2E
ALL YOU WANTED TO KNOW ABOUT IMAGING
Chair: T. Thomas
Siemens Ultrasound

2E-1 10:30 a.m.
(Invited)
CODED EXCITATION FOR DIAGNOSTIC ULTRASOUND:
A SYSTEM DEVELOPER’S PERSPECTIVE
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Image quality in diagnostic B-mode ultrasound is fundamentally determined by resolution and penetration. Resolution depends on the frequency and bandwidth of the transmitted pulse, while penetration depends on the pulse energy, which in turn depends on the pulse amplitude and duration. Conventionally, high bandwidth for resolution has been achieved by using a short pulse. This results in a tradeoff between resolution and penetration since a short pulse also constrains the pulse energy due to the limited amplitude that may be transmitted for regulatory or hardware reasons. Coded excitation increases the transmitted pulse duration for increased energy while retaining the resolution of a short pulse through appropriate coding on transmit and decoding on receive. Physically, pulse energy is distributed with coding over a long time interval and over a wide bandwidth on transmit that is subsequently compressed to a short time interval on receive to gain SNR without loss of resolution.

Coded Excitation has long been used in RADAR, however it has only recently been implemented on commercial ultrasound systems. This paper reviews the basic concepts behind coding and decoding for pulse compression including binary and chirp coding for both fundamental and harmonic imaging; discusses practical implementation issues related to transducer bandwidth, dynamic focusing, and frame rate; and presents clinical images and a new theoretical result that achieves complete 2nd harmonic compression simultaneous with fundamental cancellation by using quadrature signals.
ULTRASONIC SELF-NORMALIZED WAVELET-BASED DETECTION AND ESTIMATION OF UNKNOWN TRANSIENT VIBRATIONS IN COLORED GAUSSIAN NOISE AND STRONG, LOW FREQUENCY CLUTTER

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The detection and quantitation of transitory audio frequency sounds originating from within the body are useful diagnostic tools. Such sounds arising from arterial stenoses, aneurysms and arterio-venous shunts, which are often superimposed on ultrasound Doppler data, may have short durations and varying frequencies. Automated detection and estimation (characterization) of these vibrations may enhance diagnosis of these disorders. The noise may be both non-stationary and colored, but can be assumed Gaussian; the clutter due to arterial wall movement may be extremely large. Although detection of narrowband transient vibrations in stationary, white Gaussian noise has been widely addressed in the literature, detecting and estimating broader band transient vibrations in non-stationary, colored Gaussian noise with unknown variance in the presence of strong, low frequency clutter has remained a signal processing challenge. This paper addresses this challenge for broadband noise that varies slowly in time by using a binary hypothesis test for noise only, based on the continuous Morlet wavelet power spectrum normalized by adaptive noise variance estimates. The algorithm yields rough estimates of the amplitude, frequency range, time location and duration of detected vibrations. Simulated receiver operating curves are presented for transient vibrations of varying durations and bandwidths in colored and slowly time varying Gaussian noise and in 60 dB clutter. These curves indicate that this method achieves expected detection rates in excess of 99.8% at false alarm rates of 0.1% for (signal-on) signal to noise ratios as small as 1. A comparison is included to a slight modification of Wang and Willett’s recently published self-normalizing extension of Nutall’s power law detector. Although the two detectors yield similar results in the absence of clutter, the new detector achieves the same high detection rates when clutter is present while also providing estimates of the detected vibrations’ parameters.

This work was supported by a grant from DARPA, Number N00014-96-0630.
MEASUREMENTS COMPARING THE LINEARLY PROPAGATED FIELD USING AN EFFECTIVE APODIZATION AND THE NONLINEARLY GENERATED SECOND HARMONIC FIELD

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BACKGROUND: We have previously introduced the concept of “effective apodization” as a linear description of the nonlinearly generated harmonic components of a finite amplitude ultrasonic field.

OBJECTIVE: To compare measurements of A) the nonlinearly-generated component of the ultrasonic field from a clinical imaging system at twice the transmit frequency (2f, second harmonic) with B) the linearly-propagated ultrasonic field component, transmitted at the same frequency (2f), but employing the effective apodization of the original transmit aperture.

METHODS: A phased-array imaging system (ATL HDI5000) was modified to accommodate two distinct transmit beamforming configurations: A) Riesz window apodization excited with 1.7 MHz center frequency pulses, and B) effective apodization of a Riesz window pulsed at a 3.4 MHz center frequency. In both cases a 20 mm wide aperture was focused to a depth of 100 mm. The fundamental and harmonic field components were mapped at depths from 2 to 160 mm with a mechanically scanned 0.5 mm membrane hydrophone.

RESULTS: For the non-aberrating, non-attenuating path considered, main-lobe characteristics of the linearly-propagated effective apodization transmit case are in good agreement with the nonlinearly-generated second harmonic case. Between depths of 100 to 140 mm the average deviations between the measured beam widths of the 3, 6, 10, and 20 dB down contours were 2.6%, 1.3%, 1.1%, and 3.9%, respectively. These values increased to 6.3%, 4.8%, 4.3%, 5.5% for depths from 20 to 160 mm. The presence of grating lobes with the higher frequency transmit case prohibited the comparison of side-lobe levels.

CONCLUSIONS: This work demonstrates the utility of an “effective apodization” to describe, in terms of linear propagation, the spatial characteristics of a nonlinearly generated second harmonic component of a finite amplitude ultrasonic field.

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HARMONIC BEAMFORMING: A NEW APPROACH TO REMOVE THE LINEAR CONTRIBUTION IN HARMONIC IMAGING

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Tissue harmonic imaging is a well established technique that utilizes harmonics generated by nonlinear propagation inside the body to form an ultrasound image. To achieve the expected advantages, it is essential to remove completely the contribution due to linear propagation (i.e., the fundamental echo) from the signals collected by the array, keeping only the nonlinear part of them (i.e., the harmonic echoes). As the acoustic pulses used to insonify the tissues are very short, the spectrum of the fundamental echo is wideband and partially overlapped to the spectra of the harmonic echoes. In particular, it is difficult to remove the fundamental echo by using a single band-pass or high-pass filter. A better removal can be obtained through a filter matched to the second harmonic echo, although this requires a complex implementation and an a-priori spectral knowledge. This paper proposes a new approach, called Harmonic Beamforming, that is aimed at removing the fundamental contribution by transmitting only a single pulse and without the need of any a-priori knowledge and with no significant increase of complexity. The filtering stage is realized by a simple modification of the traditional beamforming tool, by keeping its present form of implementation: just a variation of the delay values is required. In conventional beamforming the delay values depend on the steering angle, the focusing distance, and the array element index; in the proposed approach, a new delay term depending on the carrier frequency and (nonlinearly) on the element index is added to the traditional delay. This change, plus a trivial high-pass filter placed at the beamforming output, represents a new processing method that encompasses a very good filtering capability, removing the fundamental contribution much better than a traditional band-pass filter. A performance evaluation achieved through simulated signals shows that the Harmonic Beamforming obtains a removal of the fundamental echo similar to that obtainable by a matched filter and, at the same time, the resulting beam pattern matches the expected reduction of the main-lobe width.

The authors would like to thank the ESAOTE team for the kind support.

ADVANTAGES OF PROBING THE TRABECULAR BONE WITH GOLAY CODED ULTRASOUND

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Coded signals in medical ultrasound allow both frequency and penetration depth to be increased while retaining image resolution and avoiding the need to augment the transmitted peak pressure amplitude. Such approach minimizes the potential for bioeffects even if the total amount of transmitted energy is enhanced. The goal of this work was to examine the bandwidth and noise immunity requirements of Golay coded waves used to determine frequency dependent attenuation of highly absorbing and scattering biological tissues. The measurements were performed in transmission and in pulse-echo mode using both conventional, narrowband PZT ceramic transducers and wideband PZT composites operating at frequencies of 0.5 MHz, 1MHz and 2 MHz. The measurement system included custom-built Golay code transmitter, receiver electronics and PC based, off-line decoder. In vitro human heel bones with a cortical layer removed were tested and in vivo the measurements were carried out on volunteers’ heels. The results of the measurements obtained with 8 bit and 16 bit Golay codes were compared with the reference ones acquired using 2 cycles tone burst and indicated that coding faithfully retained all information related to frequency dependent attenuation. At the same time, advantageously, the coded transmission doubled the frequency range in which ultrasonic attenuation could be determined. The attenuation data obtained using narrowband and wideband composite transducers were compared and found almost identical. That indicates that the Golay coded signals are very robust, because despite their degradation due to limited bandwidth, they were successfully decompressed without loosing their coding properties. Finally, the desirable noise immunity of the Golay system was verified by performing experiments with signal-to-noise ratio of 0dB. The results indicated that under these conditions the sine-burst excitation mode failed completely while Golay coded signals allowed attenuation properties of the bone to be correctly determined.

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Session: 3E

CMUT MODELING
Chair: R. Lerch
University Erlangen

3E-1 10:30 a.m.

DERIVATION OF A 1D CMUT MODEL FROM FEM RESULTS FOR LINEAR AND NONLINEAR EQUIVALENT CIRCUIT SIMULATION

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A new method is presented, which derives a 1D model of CMUT arrays from FEM simulations using piston radiator and plate capacitance theory. The model is suitable for fast linear and nonlinear parameter optimization.