Image Cover Sheet

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TITLE

TRACKING AND CORRECTING FOR ORGAN MOTION ARTIFACTS IN ULTRASOUND TOMOGRAPHY SYSTEMS

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Tracking and Correcting for Organ Motion Artifacts in Ultrasound Tomography Systems.

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ABSTRACT: Motion artifacts have been identified as a problem in medical tomography systems. This problem, however, is well known in other types of real time imaging systems such as RADARs and SONARs. In the cases it has been found that the application of an overlap processing scheme increases the resolution of a phased array imaging system and corrects for motion artifacts as well. Reported results have shown that the problem of correcting motion artifacts in synthetic aperture applications is centered on the estimation of a phase correction factor. This correction factor is then used to compensate for the temporal phase differences between sequential sensor-array measurements in order to coherently synthesize the spatial information. This paper describes an approach which tracks the organ motion and allows the artifacts to be isolated in ultrasound tomography systems. The spatial overlap correlator processing scheme is used to coherently extend the size of the 2-D planar array. Adaptive processing of the data from the synthetically extended planar array yields improved array gains which help to counter any effects that cause artifacts.

CONCEPT OF PLANAR ARRAY ULTRASOUND SYSTEM & PROCESSINGS SCHEMES

The proposed approach uses a 2-D planar array of detectors for ultrasound tomography system applications that incorporates a 2-D overlap correlator [1,2] and an adaptive processing scheme [3]. The potential improvements from such a system are three fold. There is firstly the potential for reduction of motion artifacts by using the overlap processing scheme [1,2]. This scheme generates larger synthetic apertures. Larger apertures inherently provide improved array gain, and hence reduce artifacts due to scattering and loss of coherence because of organ motion and the human body's propagation characteristics. The second part of the work is the use of the overlap correlator [4] scheme for tracking organ motion artifacts. It has been shown, that this scheme is successful at isolating motion artifacts in conventional tomographic systems [4]. Third is the use of adaptive processing with near-instantaneous convergence for the larger synthesized planar array aperture [3] of the ultrasound system to provide improved array gain and reduce the effects that eventually produce the aforementioned artifacts.

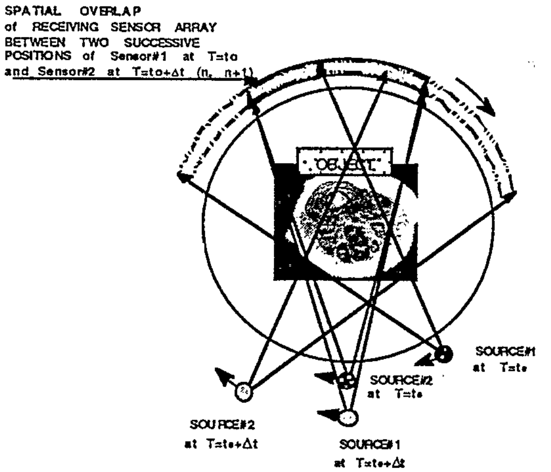

FIGURE 1. Overlap correlator scheme.

Overlap correlator The overlap processing scheme has been shown, in SONAR and RADAR applications [1,2], to increase the angular resolution (array gain) and reduce artifacts that are caused by scattering and motion. The approach of generating a synthetic aperture is based on computing an appropriate phase correction factor to synthesize extended measurements [1,2]. Extending this scheme to the case of a 2-D planar array is straightforward. The computation of the correction is still based on the comparison of spatially overlapping measurements. This phase correction factor compensates for the phase fluctuations caused by the subject's organ-motion effects and tracks the organ-motion. The extended array is then synthesized by correcting the non-overlapping measurements. It has been further shown that synthetic aperture techniques do not lead to any loss of coherence [2].

Tracking & correcting for organ motion In addition to extending the 2-D planar array aperture, the overlap correlator scheme [2] can also be used to track organ motion effects. Shown in Figure 1 is the proposed experimental implementation of this algorithm for medical tomography imaging systems. As shown in Figure 1, between two successive positions of the N-sensor receiving array, there are *(N-q)* pairs of space samples of the received field that have the same spatial information, their difference being a phase factor related to the time delay and the subject's motion while these measurements were taken. By cross-correlating the (N-q) pairs of the sensor time series that overlap, the desired phase correction factor is derived, which compensates for the time delay between these measurements and the phase fluctuations caused by the subject's motion effects; this is called the *overlap correlator*. Application of the overlap correlator to synthetic data sets has tracked the difference due to the simulated organ motion. For example, the left hand side reconstructed image of Figure 2, shows a fuzzy image that is caused by the organ-motion effects. If the measured differences by the overlap correlator scheme are reconstructed then the resulting image, which is shown by the middle image of Figure 2, clearly shows the moving organ only. These results may be of important diagnostic value, and further may be used in processing schemes for motion artifact removal [4].

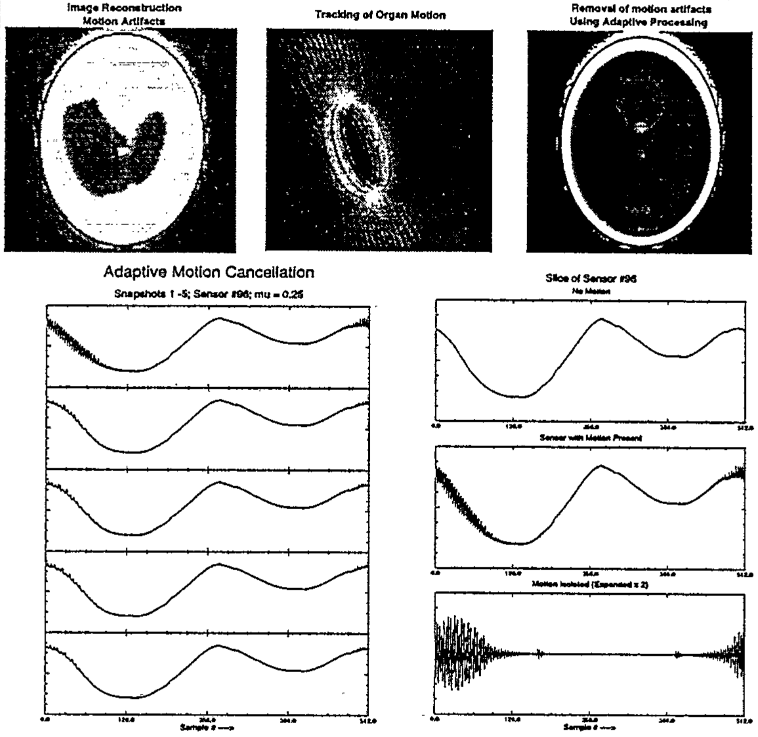

FIGURE 2

Adaptive processing The current focus of the investigation is to apply adaptive processing schemes [4] to remove the motion artifacts that have generated the fuzzy image shown at the left hand side of Figure 2. The right hand side image in Figure 2 provides the reconstructed image with corrections for the motion artifacts by using adaptive schemes. In this kind of problems it is important that the interference and noise effects, to be considered in the adaptive schemes, be identified and estimated. Preliminary results show that the tracking of the organ-motion is a first step in this direction. The lower right hand side waveforms of Figure 2 provide the time series of the same sensor and for three cases, (upper) when there is no organ motion, (middle) when there is organ motion (bottom) when the organ motion is isolated by the overlap correlator. The left hand side waveforms demonstrate the results of the adaptive processing on the time series of the sensor when there is motion present. The iteration process of the adaptive processing shows the removal of the high frequency component of the organ motion from the sensor time series. Then image reconstruction on the new set of time series provides an image without motion artifacts as shown by the upper right hand side image. In this investigation, other issues such as convergence of adaptive schemes, will be addressed to provide a system solution. The final objective is to test the theoretical developments with real data sets.

Adaptive Beamforming Finally, the use of adaptive beamforming processing with near-instantaneous convergence for the larger synthesized planar array aperture [3] of the ultrasound system would provide array gain improvements that would result in better angular and spatial resolution for the ultrasound imaging applications. This final step is very critical since implementation of adaptive beaforming into 2-D planar arrays for active applications is not a trivial task. Our approach is to minimize the number of degrees of freedom associated with the adaptation process. This is being achieved by defining 2-D planar array sub-arrays. Details about this development can be found in [3].

CONCLUSION

This paper outlines an approach that uses a planar array receiver for ultrasound tomography systems that incorporate synthetic aperture and adaptive processing schemes with near instantaneous convergence. The use of such a detector arrangement has a number of potential advantages. It has the potential of generating larger synthetic planar apertures, which helps to reduce imaging artifacts by means of improved array gain. Furthermore, the approach allows for accurate tracking of any organ motion during the data acquisition process through the use of the overlap correlator scheme. Also, the use of adaptive processing with near instantaneous convergence for planar arrays yield improved array gains and spatial resolution. This further reduces the appearance of artifacts in the final image and assists on tissue identification problems.

REFERENCES

[1] Stergiopoulos, S., *Proceedings of the IEEE*, 86(2), 201-239, February (1998).

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[3] Tawfik A., Dhanantwari A. C. and Stergiopoulos S., A "Generic Adaptive Beamforming Structure for 2-D & 3-D Arrays of Sensors", *Conference Proceedings OCEANS '97 MTS/IEEE*, 369-373, Halifax, NS, Oct.-1997.

[4] Stergiopoulos S., (Technical Project Manager), " EC-Esprit, EP 26764 New Roentgen project", Oct., 1997.

FRIDAY MORNING, 26 JUNE 1998 WEST BALLROOM A (S), 9:15 A.M. TO 12:50 P.M.

Session 5aSP

Signal Processing in Acoustics: Signal Processing for Medical Ultrasound I

Stergios Stergiopoulos, Chair
DCIEM, P.O. Box 2000, North York, Ontario M3M 3B9, Canada

Chair's Introduction—9:15

Invited Papers

9:20

5aSP1. Beyond current medical ultrasonic imaging: Opportunities for advanced signal processing. James G. Miller (Dept. of Phys., Washington Univ., St. Louis, MO 63105)

This keynote address will illustrate some aspects of current medical ultrasonic imaging and attempt to identify areas in which advanced signal processing may be able to contribute to the enhancement and extension of clinical ultrasound. Examples will be drawn primarily from echocardiography, in part because of challenges specifically associated with imaging the beating heart. The presentation will address the goals and needs of the (medical) user in order to avoid approaches which are technically elegant but clinically irrelevant. One feature peculiar to medical imaging, which limits the effective resolution to far less than the expected theoretical limit for the few hundred micrometer wavelength imaging systems in current use, is the subtle variation of elastic properties of soft tissue and the corresponding local variation in the speed of sound. Both random and systematic (for example, anisotropic) variations contribute to degradation in image quality, including the effect known as speckle. Opportunities for advanced signal processing may include not only approaches designed to enhance image resolution but also contributions to areas such as contrast agents and tissue characterization. The talk is designed to provide a broad overview which might serve as a common reference point for subsequent presentations.

10:00

5aSP2. The evolution of medical ultrasonic imaging systems. John M. Reid (Consultant 16711 254 Ave. SE, Issaquah, WA 98027)

A limit to effective soft tissue imaging is set by the acoustic properties of tissue. The attenuation is roughly proportional, and the size of a resolution element inversely proportional to frequency. Thus the number of resolution elements per image is fixed. Accordingly, acoustic frequencies from about 1 to 50 MHz are required. Effective imaging has required the development and application of innovative high-frequency hardware; particularly the transducers. These have progressed from single element types to 512 element arrays in production, with two-dimensional arrays having 1282 elements in development. The electronics now require many more channels with a dynamic range exceeding 100 dB and, with the introduction of digital methods, even multiple very fast A/D converters in the beamformer. Display devices have gone from WWII CRT's with 200 spots per radius to digital image stores on CRT's with thousands of spots available. These can now do image processing with software. The earlier systems survive in some applications that require them. The single element types are still used in high-frequency catheters, for example. The wideband transducers have opened up new methods, enhanced Doppler, contrast and tissue imaging that use a wider range of frequencies than previously possible. The single element types are still used in high-frequency catheters, for example.

10:30–10:40 Break

10:40

5aSP3. 3-D ultrasound imaging of the prostate. Aaron Fenster and Donal Downey (Robarts Res. Inst., London, ON N6A 5K8, Canada)

An important aspect that needs improvement in medical ultrasound systems is related to the 2-D imaging of the prostate. 2-D viewing of 3-D anatomy limits our ability to quantify and visualize prostate disease and is partly responsible for the reported variabilities. This occurs because: (i) the diagnostician must integrate multiple 2-D images in his mind during the procedure, leading to inefficiency and variability; (ii) The 2-D ultrasound images represent a thin plane at some arbitrary angle in the body, making it difficult to localize the image plane. To overcome these difficulties, we have developed a 3-D ultrasound system to image the prostate. Our 3-D ultrasound imaging system consists of: a conventional ultrasound machine and transducer; a custom-built assembly for rotating the probe under microcomputer control; a microcomputer with a video grabber; and software to reconstruct and display 3-D images. A typical scan of 200 2-D B-mode images takes only 13 s, and the reconstruction less than 1 s. This paper will detail the 3-D imaging approach and its use for imaging the prostate in 3-D. Various applications will be discussed related to prostate cancer diagnosis, prostate volume measurements, and 3-D ultrasound-guided therapeutic procedures such as cryosurgery.

11:10

5aSP4. The analysis and classification of small-scale tissue structures using the generalized spectrum. Kevin D. Donohue (Dept. of Elec. Eng., Univ. of Kentucky, Lexington, KY 40506), Flemming Forsberg, and Ethan J. Halpern (Thomas Jefferson Univ. Hospital, Philadelphia, PA 19107)

Conventional ultrasonic imaging systems primarily use backscattered signals for creating qualitative images that reveal large-scale structures, such as tissue boundaries. Efforts to extract additional quantitative information have resulted in limited success. The nonstationarities of the scatterers comprising biological tissue often violate conditions for applying common signal characterization and estimation methods. In addition, ultrasonic tissue properties (such as attenuation, velocity, scatterer density, size, and structure) ambiguously encode information into the backscattered signal, making it difficult or impossible to extract and quantify a single property. This paper presents the generalized spectrum (GS) as a method for analyzing and quantifying the properties of small-scale resolvable structures (on the order of 1 to 4 mm), which result from tissue structures such as lobules, ducts, and vessels. The GS extends the capabilities of power spectral density to include meaningful phase information that results from small-scale structure. The relevant properties of the GS include its ability to reduce the effects' diffuse scatterers (speckle), and permit normalization schemes that significantly limit the effects of system response and attenuation from the overlying tissue. An implementation of the GS in an analysis and classification of normal and metastic liver tissues is also described.

11:40

5aSP5. A Wold decomposition-based autonomous system for detecting breast lesions in ultrasound images of the breast. Georgia Georgiou and Fernand S. Cohen (Imaging and Comput. Vision Ctr., Dept. of Elec. and Comput. Eng., Philadelphia, PA 19104)

This paper presents an autonomous system for detecting lesions in the breast. The Wold decomposition algorithm described is used to decompose the RF echo of the breast into its diffuse and coherent components. The coherent component is modeled as a periodic sequence and the diffuse component is modeled as an autoregressive time series of low order. The parameters of the model are estimated from selected regions of the RF image and used as detection features. The database of images that was used contained 370 B-scan images from 52 patients, obtained in the Radiology department of the Thomas Jefferson Hospital. The pathologies of interest are carcinoma fibrocystic and stromal fibrosis disease and fibroadenoma. Empirical ROC techniques were used to evaluate the detection rate on single parameters of the model, such as the residual error variance and the autoregressive parameters of the diffuse component of the RF echo. The area under the empirical ROC curve for detecting lesion regions versus normal RF regions is 0.901. The area under the ROC curve for detecting carcinoma versus normal regions is 0.904. The corresponding areas for normal regions versus stromal fibrosis/fibrocystic regions and fibroadenoma regions are 0.942 and 0.899, respectively.

Contributed Papers

12:10

5aSP6. Tracking and correcting for organ motion artifacts in ultrasound tomography systems. Amar C. Dhanantwari (Dept. of Elec. and Comput. Eng., Univ. of Western Ontario, London, ON N6A 5B9, Canada) and Stergios Stergiopoulos (Defence and Civil Inst. of Environ. Medicine, P.O. Box 2000, North York, ON M3M 3B9, Canada)

Motion artifacts have been identified as a problem in medical tomography systems. This problem, however, is well known in other types of real-time imaging systems such as radar satellites and sonars. In this case it has been found that the application of an overlap processing scheme [J. Acoust. Soc. Am. 86, 158–171 (1989)] increases the resolution of a phased array imaging system and corrects for motion artifacts as well. Reported results have shown that the problem of correcting motion artifacts in synthetic aperture applications is centered on the estimation of a phase correction factor. This correction factor is then used to compensate for the temporal phase differences between sequential sensor-array measurements in order to synthesize the spatial information coherently. This paper describes an approach which tracks the organ motion and allows the artifacts to be isolated in ultrasound tomography systems. Two sources are utilized so that two sets of projections are generated that are identical in space but separated in time. Then the spatial overlap correlator processing scheme is used to synthesize the 2-D projection data coherently. This provides the desired phase correction factor, which compensates for the phase fluctuations caused by the subject's organ-motion effects and tracks the organ motion.

12:30

5aSP7. Wavefront distortion measurements in the human breast. R. C. Gauss, G. E. Trahey (Dept. of Biomed. Eng., Duke Univ., 136 Eng. Bldg., Durham, NC 27708, rgauss@acpub.duke.edu), and M. S. Soo (Duke Univ. Medical Ctr., Durham, NC 27710)

Published wavefront distortion (phase aberration) measurements for the human breast have been inconsistent, ranging from mild phase aberrations (8 ns rms) to severe phase aberrations (67 ns rms). These measurements are required to specify arrays and assess the potentials of and appropriate algorithms for adaptive imaging. They require high interelement uniformity so that receive signal variations between elements can be attributed to wave propagation effects. Array elements must be small to minimize the integration of the arriving wavefront across the face of the element. The array aperture must be large enough to allow target visualization and to provide high correlations between neighboring elements for pulse-echo measurements. An apparatus to make concurrent pulse-echo and pitch-catch (through transmission) waveform measurements in a clinical setting has been developed. The breast is stabilized between opposing transducers with light compression. After fixing the position of the transducers, pulse-echo and pitch-catch snapshots are captured sequentially with tissue and reference phantom targets. Data were collected from four views of the left breast in 12 volunteers. The rms phase error was significantly smaller for pulse-echo measurements (25 ± 14 ns rms) than for pitch-catch measurements (60 ± 23 ns rms). [Work supported by NIH.]

12:45–1:15 Panel Discussion

510024