International Journal of Computational Acoustics, Vol. 9, No. 3 (2001)

INTERNATIONAL ASSOCIATION
FOR MATHEMATICS AND
COMPUTERS IN SIMULATION

SPEED-ACCURACY TRADE-OFFS IN COMPUTING SPATIAL IMPULSE RESPONSES FOR SIMULATING MEDICAL ULTRASOUND IMAGING

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Received 7 October 1999
Revised 7 August 2000

Medical ultrasound imaging can be simulated realistically using linear acoustics. One of the most powerful approaches is to employ spatial impulse responses. Hereby both emitted fields and pulse-echo responses from point scatterers can be determined. Also any kind of dynamic focusing and apodization can be incorporated, as has been done in the Field II simulation program. Here the transducer is modeled through a set of either rectangles, triangles, or bounding lines, so that any geometry can be simulated. The response from the transducer is found by summing the spatial impulse responses from the individual elements. One of the problems in using spatial impulse responses is the abrupt changes in the responses due to the sharp transducer boundaries. Sampling the responses directly therefore have to be done at very high sampling frequencies to keep the shape and energy of the response. The high sampling frequency is unnecessary in the final signals, since the transducers used in medical ultrasound are band limited. Approaches to reduce the sampling frequency are, thus, needed to make efficient simulation programs. Field II uses time integration of the spatial impulse responses using a continuous rather than discrete time-axis. This preserves the energy in the responses and makes it possible to make sub-sample interval delays for focusing. The paper discusses the consequence of the integration for the rectangular elements that uses an approximative calculation of the spatial impulse responses. Data for the accuracy as a function of sampling frequency is given, and it is shown how a sampling frequency of 100 MHz gives similar results to using 2 GHz sampling of the analytic solution for rectangular elements. The spatial impulse responses for the triangular and bounding line elements are found analytically, and an iterative integration routine has to be used. The Romberg integration routine is used, and the accuracy versus sampling frequency for bounding line is shown. An increased accuracy is attained for the lines compared to the rectangles, but the simulation times are significantly higher. Line elements should therefore, in this implementation, only be used very close to the transducer, and if a very high precision is needed in the calculation.

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MECHANISM OF ACOUSTIC WAVE PROPAGATION: A REAL ROLE OF VIRTUAL SOURCES

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Received 7 October 1999
Revised 18 April 2000

The Huygens problem of self-regeneration of the acoustic wave crossing a liquid medium is discussed in the paper. Equal weight of both elastic and kinetic aspects of mechanical waves in fluids is stressed. Two types of virtual surface sources are defined, reflecting local action of the pressure and particle velocity, respectively. They are applied by the author in calculations of secondary radiation from the wave front of the plane wave. The Dirac delta impulse has been used as a waveform, the wave thus being reduced to its own front. The results have been obtained analytically, thanks to some particularly "friendly" features of the operation of convolution with the delta distribution. The paper gives formal proof to Fresnel's intuitive explanation of the mechanism of the forward-only propagation of the wave with no backward effects.

International Journal of Computational Acoustics, Vol. 9, No. 3 (2001)

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SYNTHESIS OF UNEQUALLY SPACED ARRAYS WITH ASYMMETRIC BEAM PATTERNS

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Received 19 November 1999
Revised 18 March 2000

In this paper, a novel method that is able to synthesize a desired asymmetric beam pattern by a fully optimized linear array to be used together with a narrow-band beamforming system is proposed. Generally, the methods presented in the literature optimize only the weight coefficients and do not consider the element positions. Therefore, when half-wavelength-spaced arrays are concerned, the optimized weight coefficients are valid only for a fixed steering angle. If the steering angle changes, it is necessary to recompute a new set of weight coefficients to keep the desired asymmetric beam pattern profile. The main feature of the method proposed here is that the synthesized weight coefficients keep their validity in any steering direction. This is attained by acting on both the element positions (in order to generate an aperiodic array) and the weight coefficients. To this end, a well-suited energy function has been defined and several conceptual mechanisms have been devised in order to minimize the energy function by the simulated annealing algorithm. As a result, a very flexible method is achieved to synthesize array configurations that yield asymmetric beam patterns that keep their validity in any steering direction without need for any update.

International Journal of Computational Acoustics, Vol. 9, No. 3 (2001)

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COMPUTERS IN SIMULATION

REAL-TIME DECONVOLUTION IN ULTRASONIC IMAGING SYSTEMS

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Received 12 June 1999
Revised 10 January 2000

We address the problem of improving the lateral resolution of ultrasonic images by a regularization technique in the wavelet domain. With a very low additional computational cost, the proposed approach increases the efficiency of the standard regularization technique because it efficiently remove the additive noise. Under the assumption that the point spread function is known, we applied our restoration technique to both synthetic and real ultrasonic imaging data. Moreover, experimental results show that the proposed method reduces also speckle artifacts, which generally are enhanced by the deconvolution.

TIME REVERSAL IN ACOUSTICS*

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Received 22 September 1999
Revised 29 September 2000

The objective of this paper is to show that time reversal invariance can be exploited in acoustics to create a variety of useful instruments as well as elegant experiments in pure physics. After a description of time reversal cavities and time reversal mirrors, a comparison between time reversal techniques and phase conjugation methods will be given. To illustrate the robustness of time reversal mirrors, several experiments conducted in multiply scattering media, in waveguides and in chaotic cavities will be presented. Finally, various applications of time reversal mirrors in medical therapy and in non-destructive testing will be discussed.

*Invited Lecture given at ICTCA'99, the 4th International Conference on Theoretical and Computational Acoustics, May 1999, Trieste, Italy.

International Journal of Computational Acoustics, Vol. 9, No. 3 (2001)

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COMPUTATION OF THE ULTRASONIC FIELD RADIATED BY SEGMENTED-ANNULAR ARRAYS

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Received 19 September 1999
Revised 20 March 2000

A method for computing the ultrasonic field radiated from segmented annular arrays is presented. Using the well known convolution-impulse response approach, an analytical expression for the spatial impulse response velocity potential from a segmented annular transducer valid for all spatial points is obtained. The array field is then calculated by superposition. The proposed solution allows us to predict transient and continuous wave pressure fields from segmented annular arrays without requiring any far-field or paraxial approximation. In order to evaluate the proposed method, an analysis of efficiency versus accuracy of the computational results is also incorporated.

International Journal of Computational Acoustics, Vol. 9, No. 3 (2001)

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NUMERICAL TECHNIQUES FOR MODELING DOPPLER ULTRASOUND SPECTRA SYSTEMS

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Received 27 August 1999
Revised 1 March 2000

Evaluation of blood-flow Doppler ultrasound spectral content is currently performed on clinical diagnosis. Since mean frequency and bandwidth spectral parameters are determinants on the quantification of stenotic degree, more precise estimators than the conventional Fourier transform should be seek. This paper summarizes studies led by the author in this field, as well as the strategies used to implement the methods in real-time. Regarding stationary and nonstationary characteristics of the blood-flow signal, different models were assessed. When autoregressive and autoregressive moving average models were compared with the traditional Fourier based methods in terms of their statistical performance while estimating both spectral parameters, the Modified Covariance model was identified by the cost/benefit criterion as the estimator presenting better performance. The performance of three time-frequency distributions and the Short Time Fourier Transform was also compared. The Choi–Williams distribution proved to be more accurate than the other methods. The identified spectral estimators were developed and optimized using high performance techniques. Homogeneous and heterogeneous architectures supporting multiple instruction multiple data parallel processing were essayed. Results obtained proved that real-time implementation of the blood-flow estimators is feasible, enhancing the usage of more complex spectral models on other ultrasonic systems.

International Journal of Computational Acoustics, Vol. 9, No. 3 (2001)

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INFLUENCE OF THE INTER-ELEMENT COUPLING ON ULTRASOUND ARRAY RADIATION PATTERNS

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Received 20 June 1999
Revised 3 March 2000

It is well known that the performances of the acoustic imaging arrays are degraded by the inter-element coupling sustained via the backing, the matching layers, and the kerf filler. The filling material inserted between the elements gives mechanical robustness to the array, but acts as a path of interaction, transmitting, between the elements, shear and lateral compressional forces. In this work, the effect on the array radiation pattern of the cross-coupling due to the filling material is investigated. A hybrid experimental–numerical technique is used. Two groups of five elements of a commercial array transducer were isolated and in one group the kerf filling material was removed. The cross-coupling waveforms, captured with a mechanical probe of small dimensions in contact with the emitting surfaces of the elements, were recorded for filled and unfilled groups of elements when: only the central element of the group was driven; all the elements were driven with the same pulse applied at the same time; all the elements were driven with the same pulse, but inverting the polarity alternately. This latter case refers to the worst coupling situation caused by the shear forces exerted between the elements. Fourier transforming the temporal signals, the cross-coupling transfer function of each element was computed and the radiation pattern was simulated by a numerical model based on the Rayleigh–Sommerfeld integral. Comparing the radiation patterns for filled and unfilled groups of elements, for the three cases mentioned above, a good estimation of the influence of the filling material is obtained.