A System Integrating HIFU Exposure Capabilities with Multiple Modes of Synchronous Ultrasonic Monitoring

Robert Muratore[*], Frederic L. Lizzi[*], Jeffrey A. Ketterling[*], Andrew Kalisz[*], Richard B. Bernardi[†], and Christopher J. Vecchio[†]

[*] *Riverside Research Institute, 156 William St Fl 9, New York NY 10038-2609 USA*
[†] *Spectrasonics Imaging, Inc., 489 Devon Park Dr Ste 301, Wayne PA 19087-1809 USA*

Abstract. A versatile biomedical ultrasound system has been developed and tested. The system controls and monitors high-intensity focused ultrasound (HIFU) exposures designed to produce therapeutic tissue lesions primarily by thermal phenomena. The system is used with custom HIFU transducer arrays that contain central diagnostic transducer arrays. The diagnostic and visualization functions are performed using a subsystem that provides full digital control over high-resolution diagnostic ultrasound arrays. Custom software controls all aspects of the imaging (e.g., electronic focusing and frame rates) with scripts and a graphical user interface. The HIFU transducer is excited using a 16-channel power amplifier controlled by a digital subsystem and waveform synthesizers. Software operator control is also provided for desired HIFU exposure parameters (apodization, frequency, time duration, focal length, intensity) and a variety of synchronous excitation modes for the HIFU and diagnostic arrays.

INTRODUCTION

A versatile system has been developed to evaluate integrated exposure and monitoring capabilities for ultimate clinical applications of high-intensity focused ultrasound (HIFU) in cardiology and cancer therapy. The system employs transducer assemblies that comprise HIFU arrays with central diagnostic arrays for positioning and synchronous monitoring of induced tissue state changes. Both transducer arrays are operated under digital control enabling diverse exposure modes and visualization procedures, which include conventional ultrasonic imaging modes and advanced modes employing digital analysis of radio-frequency (RF) ultrasound echo signals.

The system is now operational and tests of basic performance have been successful. The system consists of the transducer assembly, a digital imaging system, a HIFU excitation system, and an RF data acquisition system. All operations are run under the control of a single personal computer to integrate all functions. Subsystems are described in the following sections.

CP754, *4th International Symposium on Therapeutic Ultrasound*
edited by G.R. ter Haar and I. Rivens

IMAGING SYSTEM

The ultrasonic imaging system is an ultrasound engine (model AN2300, Analogic Corp., Peabody MA USA) that provides digital control over all conventional imaging procedures with a variety of ultrasonic arrays. Our current system employs a B-K Medical (Copenhagen, Denmark) model 8663 phased array (48 element; dynamic focusing from 5 to 57 mm), which can be operated between 5 and 7.5 MHz.

The imaging engine runs under control of an internal personal computer, which also serves as the central interface to other systems. This computer provides control over transducer excitation and dynamic focusing; it also permits control of tissue visualization using B-mode, Doppler, and harmonic imaging.

The system has been specially augmented to provide ECG triggering and to allow synchronous diagnostic imaging with HIFU exposures.

HIFU EXCITATION SYSTEM

The HIFU excitation system, developed by Spectrasonics Imaging, Inc. (Wayne PA USA), currently provides 16 independent channels (expandable) to drive HIFU arrays. Each channel supplies a pre-programmed excitation waveform to electrodes of the HIFU array using special-purpose C language APIs to control apodization, focusing, repetition rates, and power levels for each HIFU channel. Scripts and user-friendly menus expedite HIFU-beam control.

TRANSDUCER ASSEMBLY

Currently, the system is employed with an initial set of HIFU transducers, each of which has a central diagnostic array. These HIFU transducers (Sonic Concepts, Inc., Woodinville WA USA) have center frequencies of 5 MHz, outer diameters of 33 mm, and focal lengths of 35 mm. Central 14 mm diameter apertures accommodate coaxial diagnostic arrays.

Three types of HIFU transducers have been constructed: spherical cap, 5-element annular array, and 5-element strip array. The strip-electrode transducer provides a variety of asymmetric focused beams designed to provide “paddle-shaped” lesions with controlled aspect ratios. These asymmetric beams can expedite treatment of large tumor volumes [1].

All transducers have now been successfully tested with the complete system.

INTEGRATED OPERATIONAL MODES

The system can execute a number of special operational modes in addition to conventional visualization. All of these use RF echo-signal acquisition from the diagnostic transducer. They currently employ rapid off-line processing but facilities are being implemented for future on-line application.

The first mode (harmonic) launches a short (µs) pulse from the HIFU transducer and employs the diagnostic array in a receive mode. Acquired RF echo signals are then digitally filtered to compare fundamental-frequency signals with higher-order harmonics. The purpose of this mode is to detect two phenomena: harmonic levels in the incident HIFU beam which can affect absorbed dose levels, and bubbles induced by cavitational, vaporization, or degassing during HIFU exposures [2].

The second mode acquires RF pulse-echo data (with the diagnostic transducer) during brief examination periods interspersed in HIFU excitation pulses. This mode supports ultrasonic spectrum analysis to monitor the fine-scale morphology changes induced during ultrasonic HIFU and hyperthermia [3].

The third mode involves transient radiation-force elastography to sense changes in tissue stiffness and attenuation induced by HIFU exposures [4, 5]. In this mode, the HIFU transducer generates a relatively short (ms) push pulse and the diagnostic transducer is used to track fine tissue motion induced by radiation force. The technique employs RF cross-correlation algorithms for this tracking. Measurements are made before, during, and after HIFU exposures to monitor tissue changes.

SUMMARY

An integrated HIFU system combining synchronous exposure and monitoring modes has been implemented and tested. The system provides a framework for current *in-vitro* and *in-vivo* experiments and will be used as the basis for further expansions in terms of transducers, functions, and on-line monitoring.

ACKNOWLEDGMENTS

This work was supported in part by Bioengineering Research Partnerships grant 5R01 CA84588 awarded by the National Cancer Institute (USA) and the National Heart, Lung, and Blood Institute (USA).

REFERENCES

1. F.L. Lizzi, M. Astor, C. Deng, A. Rosado, D.J. Coleman, and R.H. Silverman, "Asymmetric focussed arrays for ultrasonic tumor therapy," in *Proceedings of the 1996 Ultrasonics Symposium*, edited by M. Levy et al., Institute of Electrical and Electronics Engineers, Piscataway, 1997, pp. 1281-1284.
2. Y. Hui, P. Phukpattarnont, and E.S. Ebbini., "Nonlinear methods for visualization of HIFU-induced lesions," in *Conference Proceedings of the 2nd International Symposium on Therapeutic Ultrasound*, edited by M.A. Andrew et al., Seattle: Center for Industrial & Medical Ultrasound, University of Washington, 2002, pp. 282-289.
3. F.L. Lizzi, M. Astor, T. Liu, C. Deng, D.J. Coleman, and R.H. Silverman, *Int. J. Imag. Sys. Tech*., **8,** 3-10 (1997).
4. F.L. Lizzi, R. Muratore, C.X. Deng, J.A. Ketterling, S.K. Alam, S. Mikaelian, and A. Kalisz, *Ultrasound Med. Biol*., **29**(11), 1593-1605 (2003).
5. K.R. Nightingale, M.L. Palmeri, R.W. Nightingale, and G.E. Trahey, *J. Acoust. Soc. Am*. **110**, 625-634 (2001).

e-mail contact: muratore@rrinnyc.org