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Development of an Automated Framework for High Intensity Focused Ultrasound Simulations

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High Intensity Focused Ultrasound (HIFU) technique is a noninvasive medical method for localized tissue heating, used mostly in treatment of tumors. The modality of HIFU utilizes focused ultrasound to raise the temperature of the tumor tissue in small localized volumes, resulting in necrosis. The ablation of the whole tumor, while taking into consideration all safety aspects of the treatment, is a time consuming, but requires at the same time expertise and accuracy. Treatment with reduced time as well as enhanced safety need fundamental innovations on HIFU technologies like transducer architecture and beam focusing to enable fast ablation of large tumors. Therefore, it is favorable to use computer models and simulation for therapy planning. HIFU simulations are required to support the development of the HIFU device as well as the planning of noninvasive treatments.

This paper presents the automated optimization framework to seamlessly integrate simulation process which performs from the device design to therapy planning. It consists of three processes: a) design of a random transducer array, b) design of both multi-focus patterns and a sparse array, and c) treatment planning of scanning time and path. Overall procedure of the optimization framework is shown in Figure 1. In the framework, the 3D acoustic pressure field is calculated by using the Rayleigh-Sommerfeld diffraction integral [5] and the 3D temperature distribution in tissue is modeled by using the Pennes' bioheat transfer equation (BHTE) [2]. For the optimization, Genetic Algorithms (GAs) [1] are entirely used from the 1^{st} process to the 3^{rd} process.

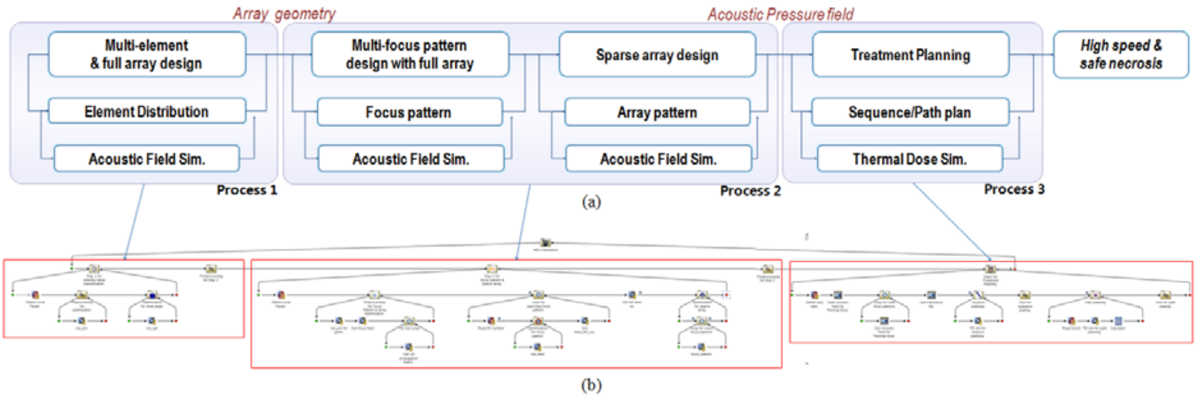

Figure 1: An optimization framework for HIFU simulations (a) a schematic diagram for simulation (b) simulation workflow implemented in commercial software Isight.

Figure 2 demonstrate the results of each procedure of the automated optimization framework. Given the initial geometry of the transducer array and total control points in the focal plane, random transducer array was generated in the 1st process by maximizing the steering angle of a single focus with minimal grating lobes. Then for fast ablation in the 2nd process, the total number of control points was partitioned into groups of multiple-focus patterns with minimal grating lobes outside region of interest. [3] Besides, the design of a sparse array was performed in order to reduce the number of array elements and RF drive channels required for practical implementation. [4] In the 3rd process, scanning sequence of the patterns was determined for the uniform necrosis volume in advance. Then, treatment planning of scan time/path with the prepared sequence was performed to minimize the overall treatment time while keeping the thermal dose out of the target region below predetermined limits.

The proposed automated framework for HIFU simulations allows us not only to quickly develop ultrasound phased array models for therapeutic applications but also to rapidly perform the treatment planning by taking into consideration the safety of the patients.

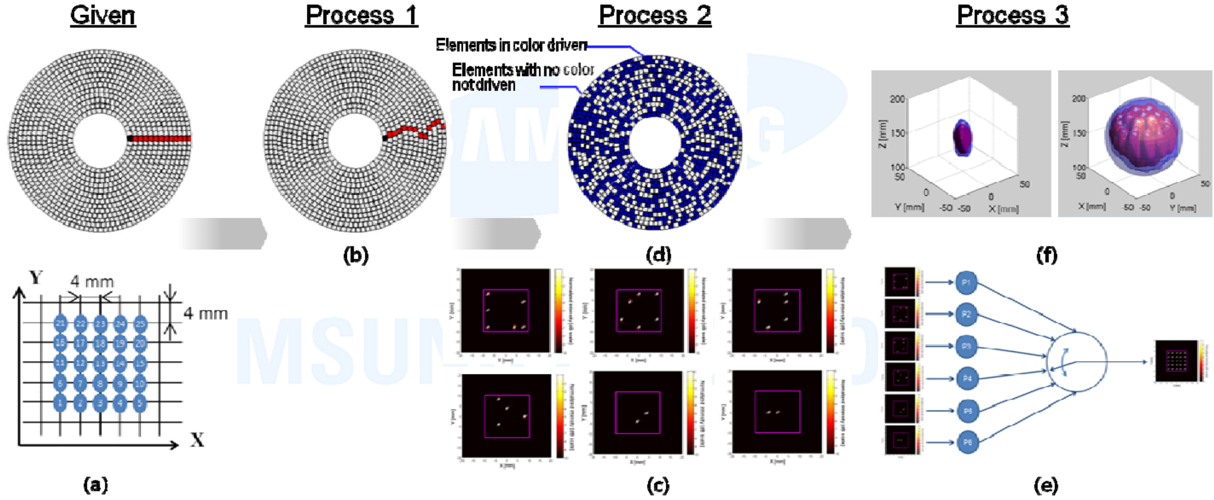

Figure 2: Results of each procedure of the framework (a) Initial geometry of the phased array with 1017 elements and 25 control points on the focal plane (b) Random transducer array (c) Intensity distribution for multiple-focus patterns (d) Configuration of a sparse array (e) Temporal switching for multiple focusing (f) Thermal dose distribution.

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