SIMULATION OF ACOUSTIC FIELDS FROM MEDICAL ULTRASOUND TRANSDUCERS[#]

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Abstract: Field II program, developed by Jørgen Arendt Jensen, can simulate all kinds of ultrasound transducers. With this program it is possible to control dynamically the focusing and apodization of the transducers which makes it possible to simulate various types of ultrasound imaging systems. The simulation method can be used for optimization of array parameters in the design stage and also for education and research purposes. In intravascular sonography or low depth imaging the desired tissue is very close to the transducer therefore it is useful to apply this method of good accuracy both in near-field and far-field. In this paper the authors make a presentation of this program giving examples of transducers simulation and they have introduced an improved simulation method for calculating the ultrasound field of arrays. Simulation results are shown for different parameter settings to evaluate the effects of every parameter in the 2-D arrays field.

Key words: acoustic field, simulation, ultrasound transducers, tissue.

INTRODUCTION

In the biomedical field, the systems for images processing are very important calling for new techniques, much more advanced and performing than they used to be, in order to provide a correct analysis and diagnosis. Among the medical techniques using computer sciences, it can be mentioned: scintigraphy, echography, tomography, radiography, quantitative microscopy, nuclear magnetic resonance. Ultrasound, widely used in many areas of medicine, provides a safe and efficient means for diagnosis and therapy. When the medium becomes complex solving the wave propagation formula becomes virtually impossible. Modeling becomes much more complex inside the body because the ultrasound propagation speed is different for each tissue and it is known that tissues are not a homogeneous medium for ultrasound wave propagation. Therefore, it is important to know how the ultrasound wave is generated and the ultrasound wave beam shaped. First, it is

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simulated an ultrasound transducer to predict the beam shape and then the transducers are adjusted until the beam shape is close or equal to the desired one. To do so, many programs are developed in order to facilitate simulation on ultrasound transducers.

The role of the acoustic transducer in high-quality image acquisition from medical ultrasound scanners is very important. In fact it determines the quality of an image. There are considerable efforts in designing transducers and determining the characteristics of the emitted field. Field II program [2], developed by J.A. Jensen, can simulate all kinds of ultrasound transducers using linear acoustics and it utilizes the Tupholme-Stepanishen method for calculating spatial impulse responses. The program is capable of calculating the fields for both the pulsed and continuous wave case for a large number of different transducers and allows visualization of simulating transducers. The calculation of the spatial impulse response assumes linearity [3] and any complex-shaped transducer can therefore be divided into smaller apertures and the response can be found by adding the responses from the sub-apertures.

Medical ultrasound imaging illustrates this: a conventional 2-D scan is done with 1-D arrays with 32 to 192 elements; 3-D ultrasound imaging requires 2-D arrays in order to perform a volumetric scan without mechanical movement. Such arrays require thousands of elements in order to cover the desired aperture. The purpose of the work presented here is to give a coherent analysis of 2-D array design and properties. We begin with an introduction to array processing and then proceed to find the best solution of 2-D arrays. The optimization criteria attempt to design beam patterns with small main lobe width and small side lobes. The study aims at finding a beam pattern with minimal peak side lobes. One has the freedom to choose from the methods presented here, a design method likely to lead to the best beam pattern pressures produced by these arrays transducers, in order to optimize their design for a particular application.

To determine the spatial impulse response it is assumed that a transducer generates a delta-function motion. Its temporal response can be determined for all field points. This is the spatial impulse response. Once this is known, a field can be determined for any transducer driving function.

EXPERIMENTAL

The focusing and apodization of the transducers can be controlled dynamically, and thus it is possible to simulate all kinds of ultrasound imaging systems. For simulation purpose the ultrasound package FIELD II [4] for Matlab was used.

The program consists of three types of m-functions which are used to initialize the program, defining and manipulating transducers, and to perform calculations. The names of initializing routines are preceded by field, the transducer commands by xdc, and the calculation routines by calc. Help in using the routines can be obtained by typing help <routine name>.

The calculation of the spatial impulse response assumes linearity and any complex-shaped transducer can therefore be divided into smaller apertures and the response can be found by adding the responses from the sub-apertures.

The executable code for the program can be downloaded, free of charge, from the http://www.es.oersted.dtu.dk/staff/jaj/field/, and can be run from a directory by writing:

path(path,'/home/user/field_II/m_files');

field_init.

The command field_init must be the first routine that is called and initializes the Field II program system.

Field simulations follow this type of a sequence:

- define an array;
- define the impulse response of a transducer element from that array;
- define the waveform of the transmitted signal;
- define targets that will be imaging;
- calculate the scattered response from these targets for each image line position;
- envelope detect and compress;
- display the image.

According to our aim, in order to view the shape of transducers this program has been modified by adding show_xdc routine.

Three types of transducers were simulated: linear, concave and convex array. For the same initial data, the transducer frequency was modified and compared with the final display.

To increase the accuracy of the simulation it was created a linear array with 16 elements, divided into 2 by 3 mathematical elements (Fig. 1).

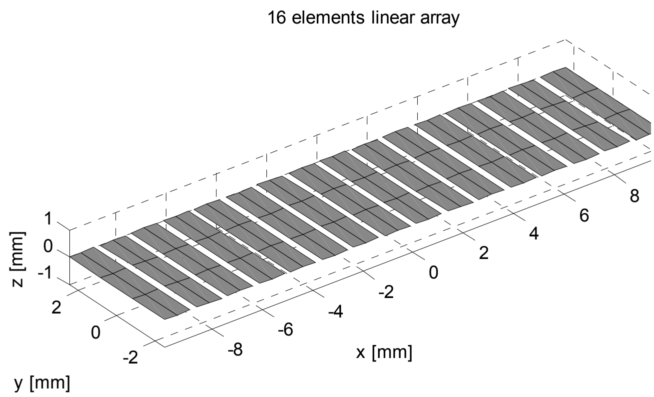

Fig. 1. Linear array transducer.

The initial parameters are: height of element 5 mm; width of element 1 mm; distance between transducer elements 0.25 mm; number of elements 16.

For the concave transducer simulated, the parameters are (Fig. 2): transducer radius, 8 mm; geometric focus point, 80 mm; size of mathematical elements, 1 mm.

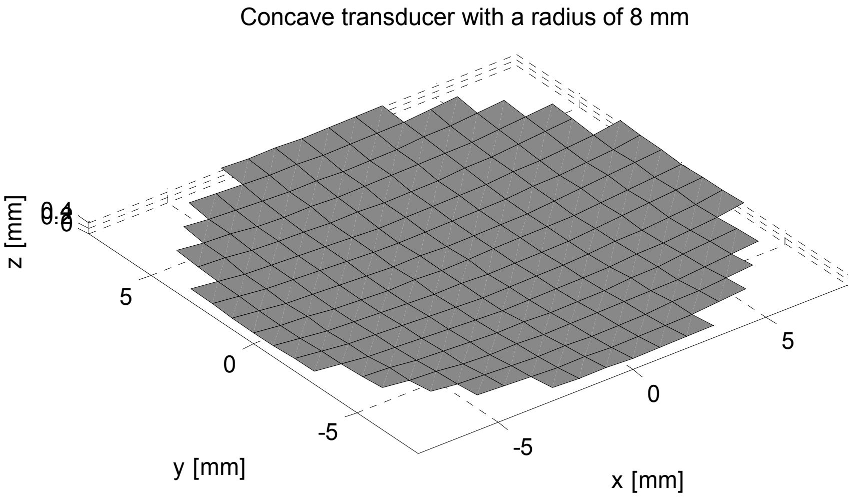

Fig. 2. Concave, round transducer with a radius of 8 mm.

The convex aperture that was created has the following parameters (Fig. 3): height of element 5 mm; width of element 1 mm; distance between transducer elements 0.25 mm; number of elements 16; convex radius 20 mm.

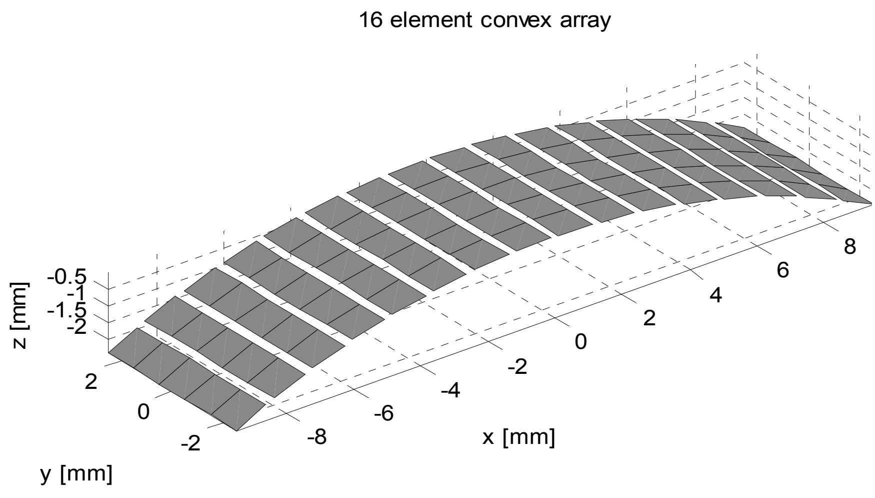

Fig. 3. Convex array.

RESULTS

The array is located on the xy plane, and the results of the acoustic field are shown in the xz plane, which is orthogonal to the middle of xy plane (Figs. 1–3). In this study we increase the frequency and modify the shape of the transducer, without changing the other parameters (sound velocity in the medium is 1540 m/s and density of the medium 1000 kg/m^3) in order to study their effect on the beam pattern.

With the same data it was determined the pulse echo field along a given set of points (this line is for x from –10 to 10 mm at a depth of 30 mm) by using all three transducers. The changes of the final display were analyzed and compared.

After the transducers had been defined, the transducers frequency was set to 3 MHz, 3.5 MHz and 5 MHz.

The amount of divergence of the far field is shown as:

$$\sin\theta = 1.22\frac{\lambda}{D} = 1.22\frac{c}{fD} \tag{1}$$

where λ is the wavelength, c is the sound velocity in the medium, f is the frequency and D shows the diameter of the transducer.

By increasing the frequency in the above equation, the width of the main lobe will decrease. The length of the near field can be calculated by:

$$x \approx \frac{D^2}{4\lambda} = \frac{D^2 f}{4c} \tag{2}$$

which shows that, by increasing the frequency, the maximum pressure point distance from the transducer will increase [1].

The effect of both frequency and shape of the transducer and the point spread function for each transducer, at 3 MHz, 3.5 MHz and 5 MHz are presented in Figures 4, 5, and 6.

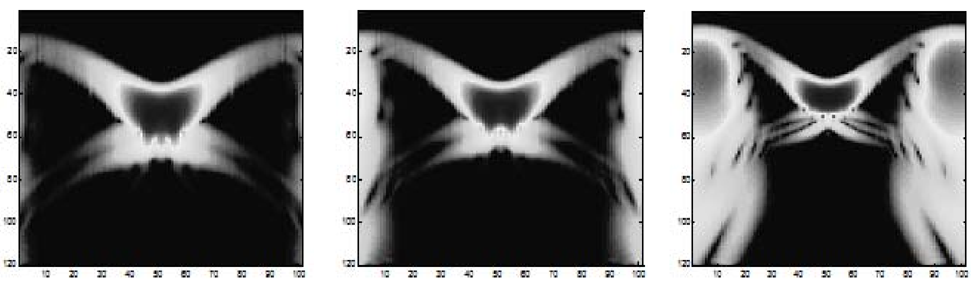

Fig. 4. Amplitude response for linear array.

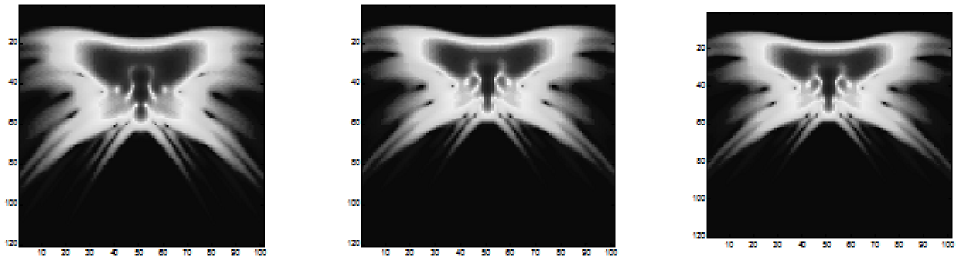

Fig. 5. Amplitude response for concave transducer.

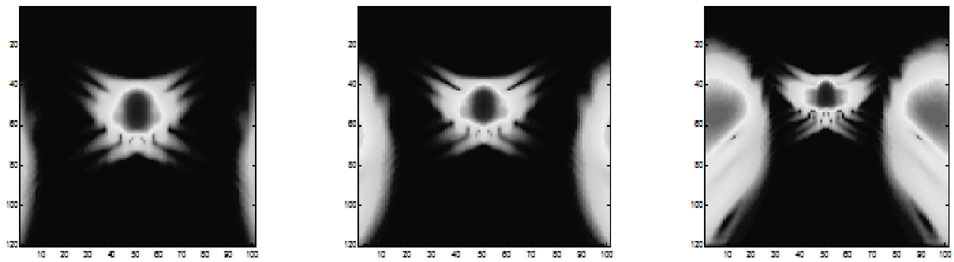

Fig. 6. Amplitude response for convex array.

CONCLUSION

The paper attempts to present a coherent analysis of 2-D array transducer design and properties. The paper has introduced an improved simulation method for calculating the ultrasound field of arrays. The method uses the accurate calculation of the Rayleigh integral for a transducer element in an array and thus, by properly shifting the result, the field of other transducer elements is obtained and the effects of all elements are subsequently added to construct the whole array field.

The quality of the image acquisition from medical ultrasound scanners is determined by the acoustic transducer. Therefore, researchers are interested in developing new methods to design transducers and determine the characteristics of the emitted field.

This program is able to show the effect of changing the array's parameters such as number and size of elements, frequency, shape of transducer, excitation amplitude, sound velocity and density of the medium in which the sound propagates.

In this paper the effects of three types of array have been analyzed. The final display, the echo responses along the line of interest, shows that the best option for this data is a concave transducer at 3 MHz.

This program can be used for optimizing array parameters early in the design stage and also for education and research purposes.

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