# NUMERICAL ANALYSIS OF RADIATION CHARACTERISTICS OF ULTRASOUND TRANSDUCERS BY MEANS OF THE CONCURRENT ALGORITHM

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*The radiation characteristics of the ultrasound transducers can be calculated by means of the concurrent algorithm. This approach is necessary when the calculations are performed on a computer cluster and additionally allows to enhance greatly the overall efficiency of such an algorithm. This paper presents the analysis of radiation characteristic of a few ultrasound transducers obtained by means of the concurrent algorithm. The algorithm bases on the spatial impulse response method and is implemented on an openMosix heterogeneous cluster.*

*Keywords: ultrasound, radiation characteristics, SIR, parallel computing*

## 1. INTRODUCTION

In most cases, the aim of acoustic wave analyses is to calculate the spatial distribution of the acoustic field created by the ultrasound transducer with known geometrical properties and that is excited using a signal with known time characteristics. The radiation characteristics of the ultrasound transducers can be obtained using spatial impulse method. The spatial impulse response method is based on the assumption, that the source of an acoustic wave performs single oscillations in the form of Dirrac's impulses. This assumption allows us to analyse the acoustic system not only in the frequency domain, but also, which is most important, in the time domain. The method exploits mathematical apparatus well known in the signal theory.

In spite of prospective significant advantages, the spatial impulse method has not been used for a long time in the analysis of the acoustic transducers and head due to very high computational costs. In the recent years the dynamic progress in computer sciences and the rapidly growing computational scope of modern computer systems, has made it a useful tool for the analysis of real acoustic systems. [1-3]

The numerical algorithm proposed by the authors, is based on the analysis of the acoustic system in the time domain . As stated before, one of the results of the time domain analysis is its quite high demand for computing power. To gain an access to the necessary computing power, the authors have decided to use the high-performance computing (HPC) cluster. This fact required creating of the adequate concurrent algorithm and its implementation. As a result of the necessity of using the parallel environment to perform calculations, the presented model is designed to achieve a high level of parallelism. In effect most time and memory consuming parts are separable and can be performed on different logical processors.

## 2. THEORETICAL AND NUMERICAL BACKGROUND

The theoretical background of the model is based on the linear representation of the acoustic systems proposed by P. Stepanishen [4,5] and later used by J.A. Jensen in their papers [6,7]. The general idea consider the acoustic system under consideration as a linear one and calculates its impulse response. In the physical meaning, the *spatial impulse response* (SIR) is based on the acoustic Huyghens-Rayleigh equation [8,9]:

$$\Psi(P,t)=\frac{1}{2\pi}\int_{S'}\frac{1}{r}v_n\left(P,t-\frac{r}{c}\right)dS \tag{1}$$

where $\Psi$ denotes the acoustic velocity potential, $v_n$ is the normal velocity of the transducer surface, $r$ is the distance between the observation point and the point on the transducer surface, and $c$ is the speed of the sound in a the medium. The observation point is the point in space where the physical properties of the acoustic field are calculated.

Assuming that the velocity of the surface is uniform for the aperture under consideration, equation (1) can be rewritten in the following form:

$$\Psi(P,t)=v_n(t)\underset{t}{*}\int_{S'}\frac{1}{2\pi r}\delta\left(t-\frac{r}{c}\right)dS \tag{2}$$

The integral, which is a part of the above equation, is the transition function of the linear acoustic system (so-called spatial impulse response) and is denoted by the symbol $h$. The spatial impulse response can be treated as a time signal representing the acoustic field excited by a Dirac impulse. This means, that SIR complies with information concerning the entire frequency spectrum.

According to the signal theory and assuming a linearity of the physical parameters of the acoustic field, the spatial impulse response from the complex system of transducers can be presented as a sum of the responses from any number of subelements, which represents the actual system. This fact is quite useful for numerical computations and provides a possibility of enhancing considerably the modelling of acoustic transducers by the means of concurrent computations.

## 4. NUMERICAL RESULTS

There are a few steps in the process of modelling the spatial distribution of the acoustic field generated by the ultrasound head using the spatial impulse response method. One of the basic ones is the calculation of the spatial impulse resonse from the acoustic head divided into basic elements. Such division of the heads surface and the total SIR signal is shown on Fig. 1.

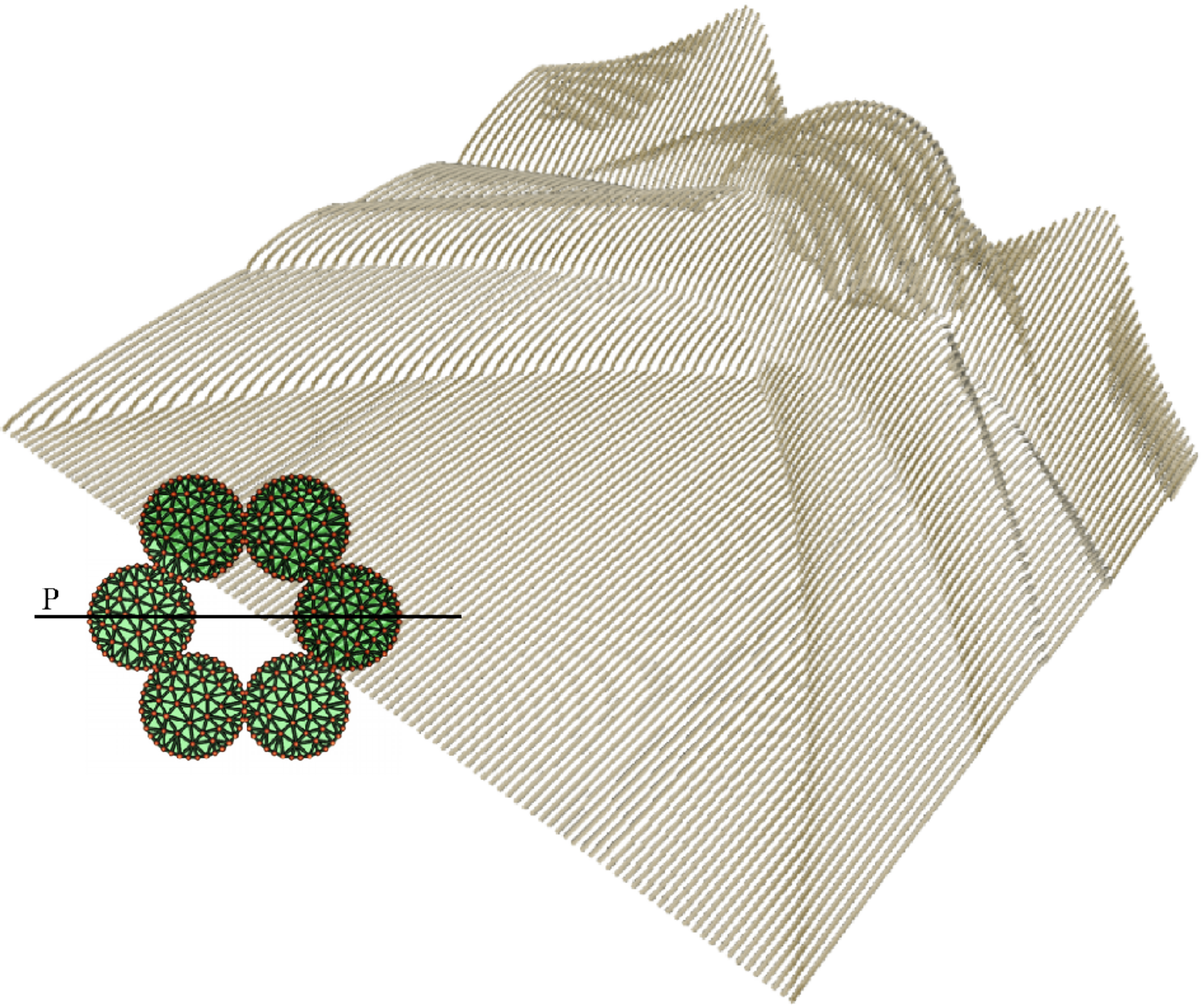


Fig. 1. Spatial impulse response signal for main acoustic axis of ring acoustic head composed of 6 circular flat transducers obtained in 100 observation points.

The 6 circular transducers are organised in ring acoustic head. The surface of the transducers is divided into 388 basic triangular elements. The SIR signal for each of the surface elements is calculated for 100 observation points evenly distributed on line “P”. On the figure the combined SIR signal for each observeation point for entire acoustic head is presented. The figure presents in quite an elegant way, the symmetry of the SIR signal for a more complicated case. The maxima corresponding with the respective transducers can be easily recognized.

One of the most important features of the presented algorithm, is its ability to calculate the spatial distribution of the acoustic field. The pressure distribution can be calculated for any arbitrary location of the calculation points. In practice, the distributions for one and two-dimensional regular grids are the most important.

The pressure distribution along the main acoustic axis are presented on Fig. 2 for various frequencies of excitation. The boundary between near and far field and its location dependency on the excitation signal frequency can be clearly seen.

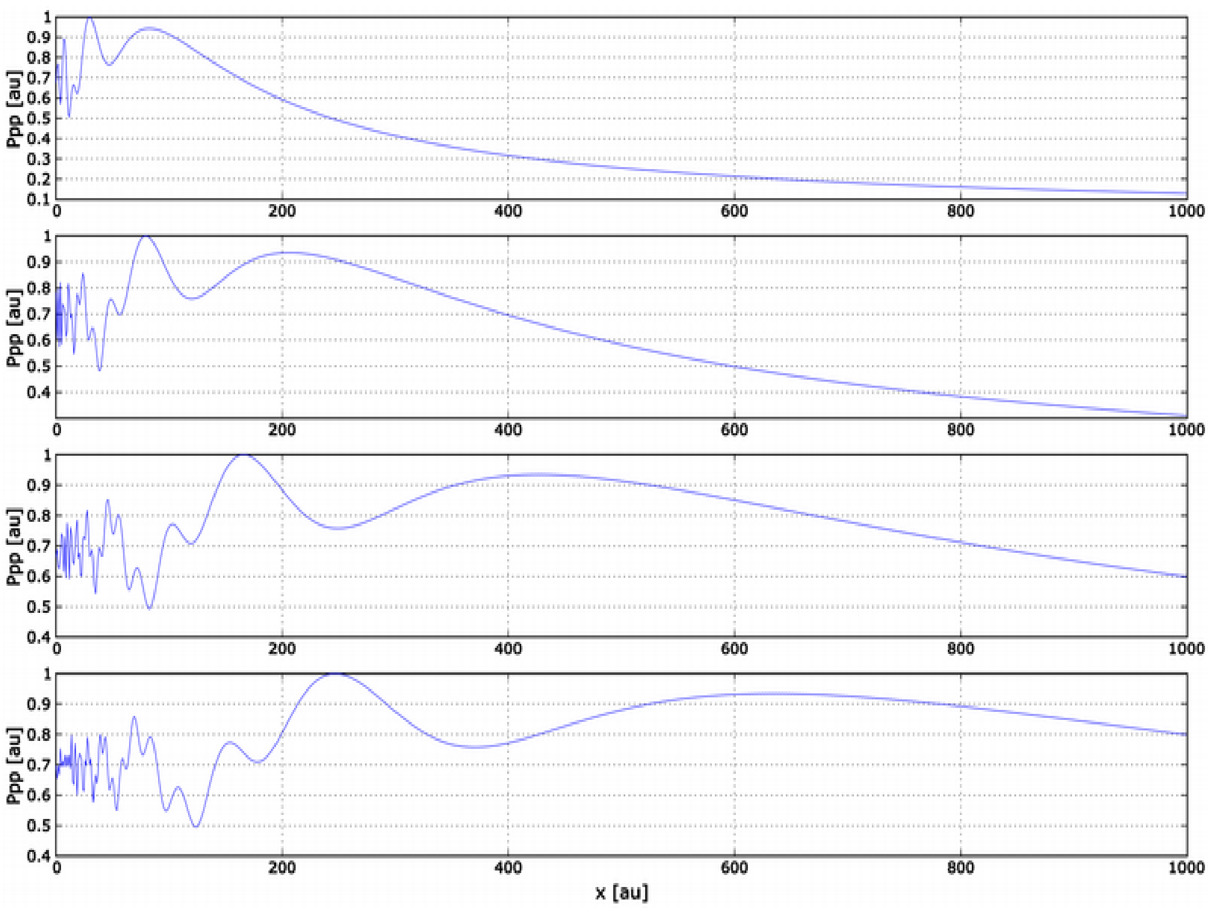


Fig. 2. Acoustic field pressure distribution generated by the circular transducer. Excitation using harmonic signal of frequency a) 100kHz; b) 250kHz; c) 500kHz; d) 750kHz.

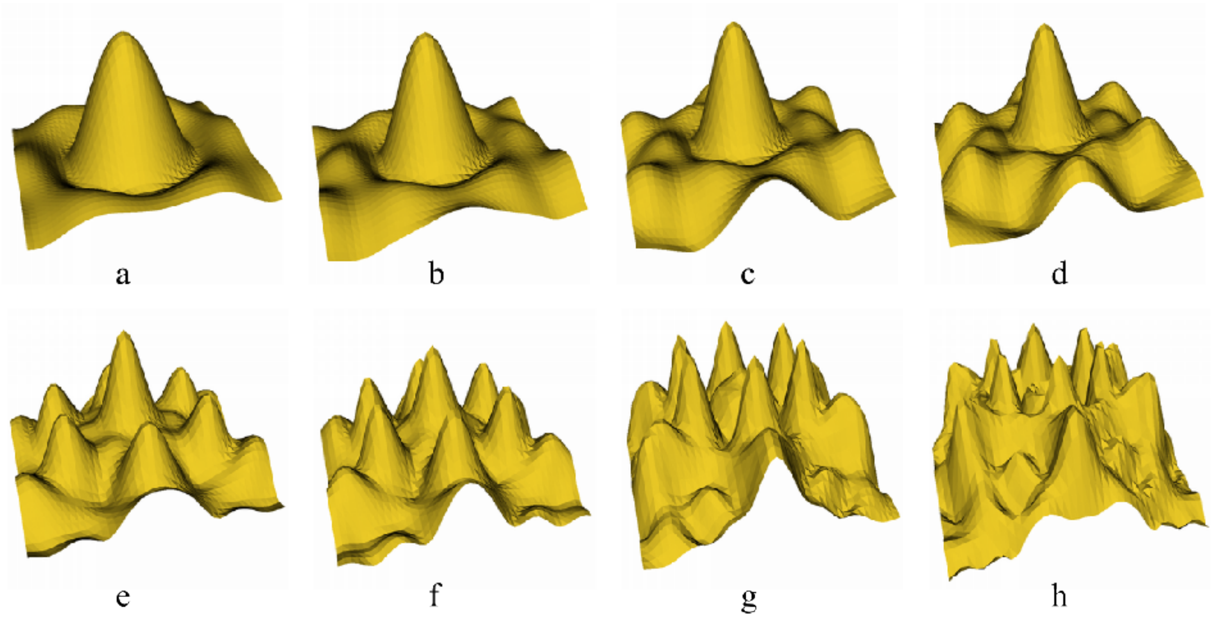


Fig. 3. Acoustic pressure distribution of ring acoustic head composed of 6 circular flat transducers. Pressure calculated for flat calculation grid located in far field (±6° on each axis). Excitation using harmonic signal of frequency a) 50kHz; b) 100kHz; c) 150kHz; d) 200kHz; e) 250kHz; f) 300kHz; g) 350kHz; h) 400kHz.

On Fig. 3. acoustic pressure distribution is obtained for the ring acoustic head composed of 6 circular flat transducers. The pressure was calculated in 1681 observation points composed into flat grid located in far field for given frequency range (50-400 kHz). On the figure the change in the head radiation characteristic can be clearly seen. With the increase in excitation frequency the main lobe is greatly decreased and the entire family of side lobes produced by the head geometry are seen.

## 3. SUMMARY

In this work the numerical method for calculation of the radiation characteristics using spatial impulse response signal method is presented. The presented method is correct for any kind of acoustic transducers and heads geometry and for any type of field grid distribution. Additionally, any kind of excitation signal can be simulated and analysed. Such combination results in powerful tool for analysis of the acoustic field distribution generated by acoustic ultrasound head of any type.

The presented method has been optimised for execution in parallel environment and tested in depth. In effect the idea of using the concurrent algorithm for SIR calculations proved useful. Also in its implementation almost ideal parallelism (over 90% of node utilization) has been achieved.

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