USim - Optimized Acoustic Echoes Simulator in Fourier domain

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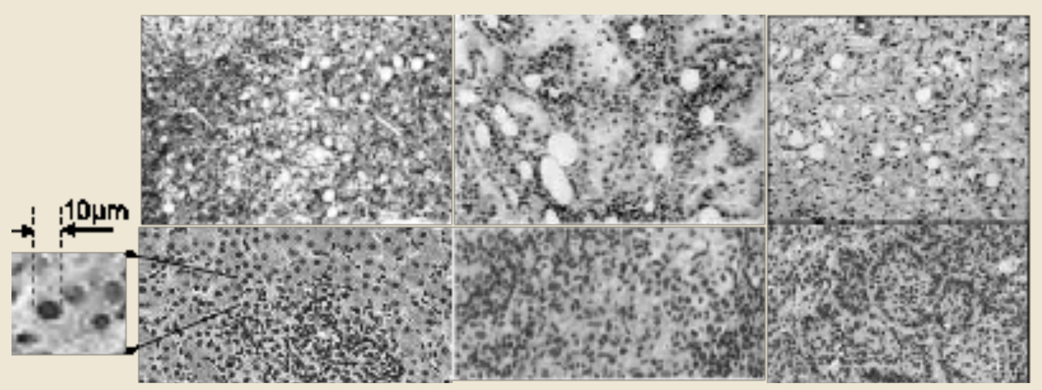
CONCLUSIONS

A toolbox for the simulation of acoustic wave fields USim, is designed to make an acoustic modeling of ultrasound propagation in tissues reliable and fast. Due to the large relative size of the phantom models and the absorption properties of tissues (viscous, nonlocal in time effects), the construction of an efficient solver in the time-space domain is impossible. The approach to computations conducted in Fourier frequency space allows increasing the efficiency of the calculations and taking into account the absorption phenomena which are significant in organic media and have a non-local description in the time-space domain

METHODS - medium definition

Although the tissues are of different types, a significant structural similarity can be observed. Ultrasonic and histopathological images of a healthy tissues show significant multi-scale uniformity of the distribution of inhomogeneities and physical parameters



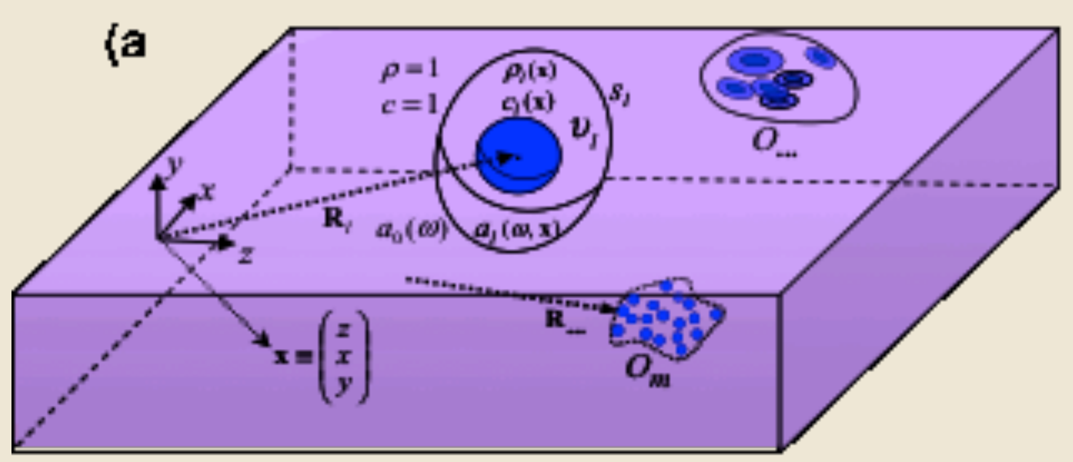
The images of the pathological or inflammation conditions of these tissues show that they are made of (cancerous) cells with dominating shapes very well described by the spheres or ellipsoids of a certain distribution of the geometrical parameters – diameters of up to 10 μ m . It is assumed, that reference medium surrounds

L bounded space regions υ . Each region υ is filled by the ll

medium with normalized density and sound speed (in particular filling can be homogeneous).

The sum of the sets υ describes the structure as immersed l

in reference medium. Space distribution of the sound speed, density:



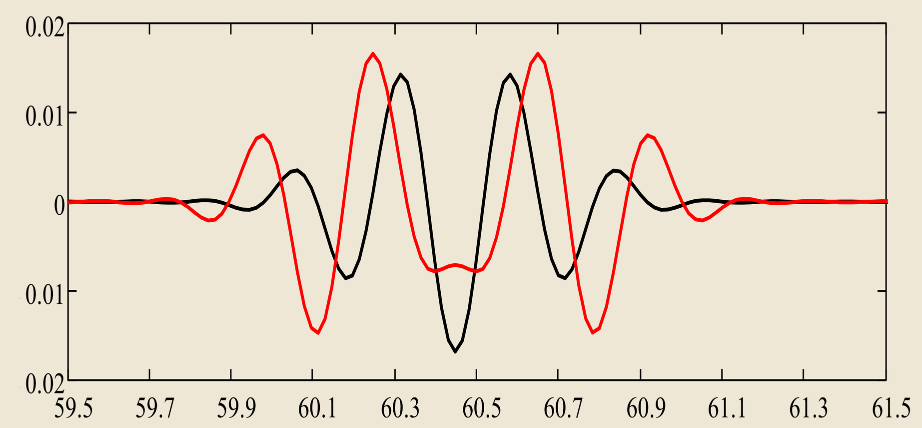
$$c^2(\mathbf{x}) = 1 + \sum_l \delta c^2(\mathbf{x}-\mathbf{R}_l) = 1 + \sum_l \chi_l \cdot (c_l^2 - 1)$$

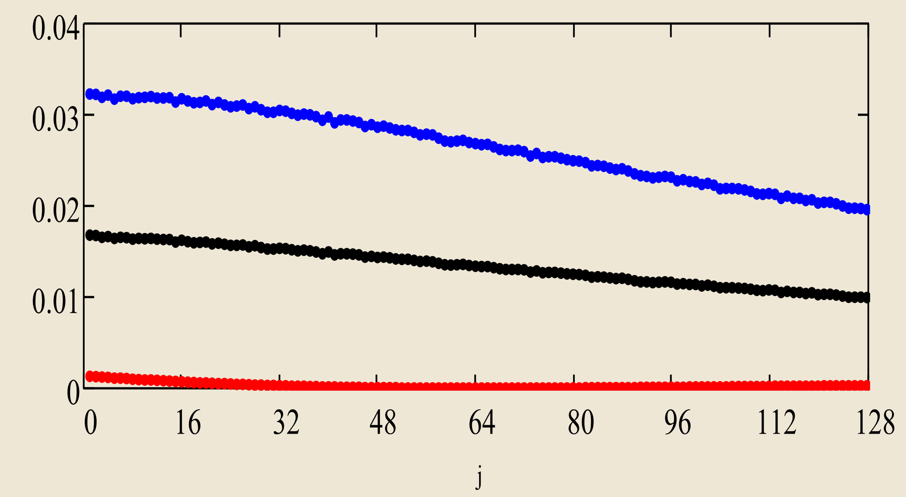
$$\rho(\mathbf{x}) = 1 + \sum_l \delta\rho(\mathbf{x}-\mathbf{R}_l) = 1 + \sum_l \chi_l \cdot (\rho_l - 1)$$

$$\begin{aligned} a(\mathbf{x},\omega) &= a_0(\omega) + \sum_l \delta a(\mathbf{x}-\mathbf{R}_l,\omega) \\ &= a_0(\omega) + \sum_l \chi_l \cdot (a_l(\omega) - a_0(\omega)) \end{aligned}$$

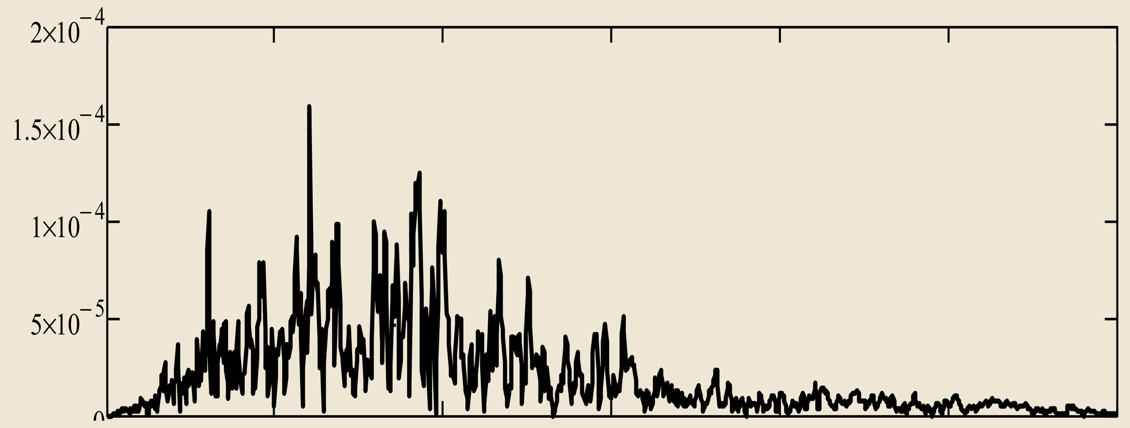
RESULTS

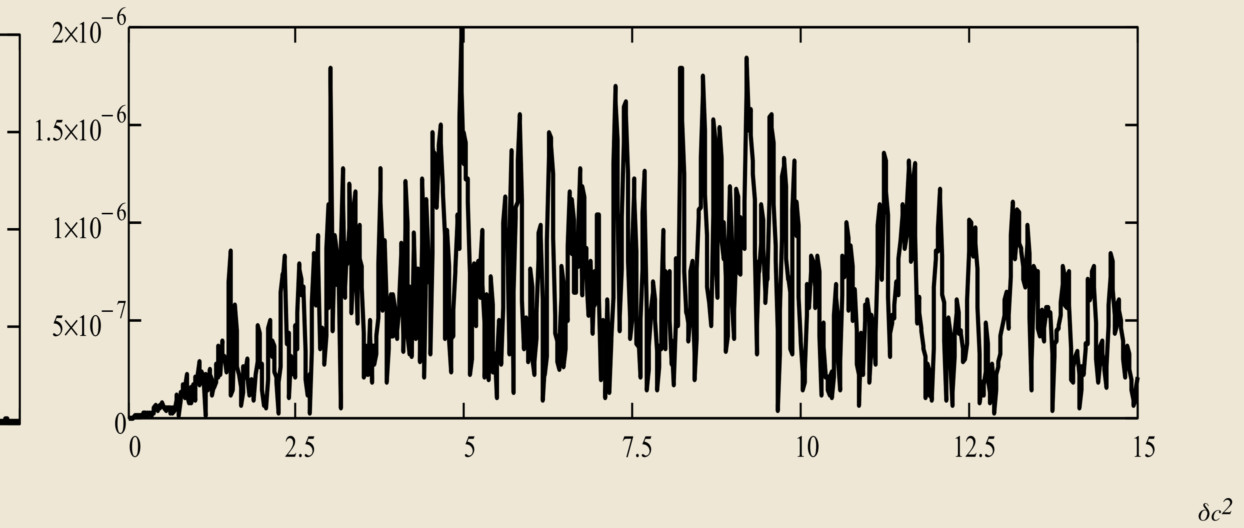
The differences in the scattered field distribution when using scatterers of different properties are shown in fig. 3. Variables δg and δc^2 correspond to relative density and square of sound speed of nonhomogeneities





influence of average size of the scatterers (balls with diameter *d*) on stochastic medium transfer function (perfect point transmitter and the same receiver) in backscattering





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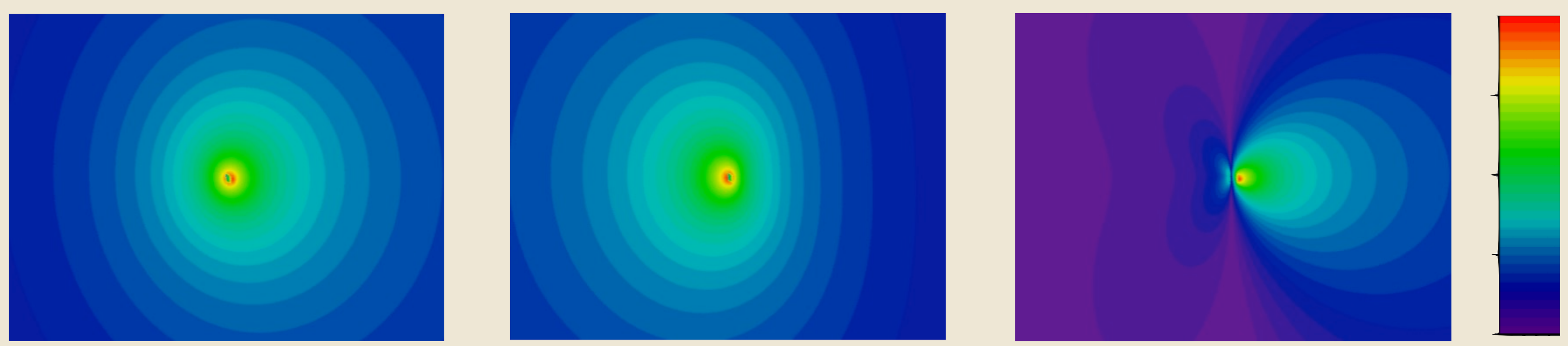
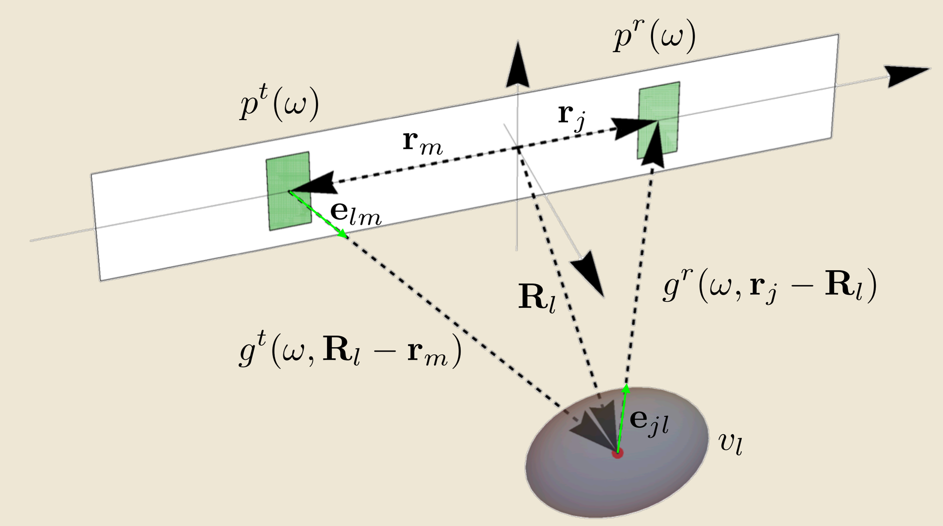


It is shown that including the density variations in the medium and finite size (not infinitesimal) scatterers can bring additional informations on the characteristics of the system.

METHODS - governing equations

The calculation method is based on the integral form of Sturm-Liouville equations obtained in [*] from Lame model of the heterogeneous medium. It is free from the limitations and errors caused by calculation on the grid and / or in the time- space regime (numerical diffusion, and other numeric unintended "physical" effects, nonlocal absorption []). All variables are normalized, which is justified by numerical analysis. In the reference medium surrounding the inhomogeneities normalized density and speed of sound are equal to 1. On the bases of the model it may be showed that the

eho E_l (ω, j, m) detected bay receiver in position $\mathbf{r}_j$ of the pulse transmitted by m-th transducer in position $\mathbf{r}_m$ and scattered on heterogeneity in $\mathbf{R}_l$ is given by



$$E_{ljm}(\omega) = p^{rt}(\omega) g^r(\omega, \mathbf{r}_{jl}) g^t(\omega, \mathbf{r}_{lm}) w_l(\mathbf{k}_{jl} - \mathbf{q}_{lm}, \mathbf{q}_{lm})$$

$$Q_l = \ln(1 + (\rho_l - 1))$$

$$V_l = 1 - \frac{(1 - 2ia_0(\omega)/\omega)}{c_l^2\,(1 - 2ia_l(\omega)/\omega\rho_l c_l^2)}$$

$$\begin{aligned} w_l(\mathbf{k}-\mathbf{q},\mathbf{q}) &= \left(V_l + k^{-2}(\mathbf{k}-\mathbf{q})qQ_l\right)\boldsymbol{\chi}_l(\mathbf{k}-\mathbf{q}) \\ &= \left(V_l + (\mathbf{e}_{jl}\cdot\mathbf{e}_{lm} - 1)\delta\rho_l\right)\boldsymbol{\chi}\left(\omega(\mathbf{e}_{jl} - \mathbf{e}_{lm})\right) \end{aligned}$$

Summing E_l (ω, j, m) over all l=1,2,...,L heterogeneities we obtain total echo detected from the medium E(ω, j,m)

Different boundary conditions for corresponding sources and detectors with different shapes can be obtained using characteristics of g^t (ω,·), g^r (ω,·)or their combinations. The values g^t (ω,·), g^r (ω,·)for any position of the scatterer, the transmitter and detector are interpolated from the pre- calculated for the particular emitter and detector type. A sampling of the fields adapted to the spatial variability of the features makes these sets small although the full description of physical and scattering potential is a 4-dimensional object

(ω;l, j,m) - a large even for the case of single-element court transmitting and

CONTACT & FURTHER INFORMATIONS

Although software is at the preliminary stage of the development , its current status can be downloaded from https://github.com/usgold/USim