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COMPARISON OF SCANNING SCHEMES FOR OPTOACOUSTIC
DIAGNOSTICS OF TURBID MEDIA

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The work is devoted to the numerical simulation of the applicability of quasi-resonant ultrasonic receivers with electronic scanning similar to those applied in USI for non-invasive optoacoustical (OA) diagnostics of turbid media under conditions of limited access to its surface. The advantage of such receivers is their ability to obtain 2D OA images of the internal structure of the investigated object with limited access area without the necessity of macroscopic motion of the acoustical head. This work was supported by RFBR (Project # 05-02-16919).

A growing interest to the optoacoustic (OA) method is observed during recent years related with the perspectives of its application for non-invasive diagnostics of biological tissues [1-6]. In particular OA method allows diagnosing soft biological tissues to the depths of about 10 cm and high-resolution detecting heterogeneities differing from the surrounding tissues by optical absorption coefficient. Hence OA tomography can appear the effective addition to the traditional methods of tomography diagnostics: ultrasonic investigation (USI), X-ray examination, MRI.

Two basic functional parts can be distinguished in the construction of OA tomograph: the source of heating radiation and the acoustical receiver. Parameters of heating source determine the spatial area of OA signal generation and the type of heterogeneities to be detected by OA tomograph. Spatial resolution of OA tomogram is generally determined by features of acoustical receiver and chosen scanning scheme. The advisability of using narrow-band ultrasonic receivers for deep OA diagnostics was demonstrated in [3]. In our works as well in works of other authors [7-11] a number of various schemes of OA measurements were considered: transmission scheme with circular tracing, a ring of stationary weakly directed acoustical transducers, single-dimensional array of receivers. All of them have their own advantages however their application becomes significantly difficult or even impossible under conditions of limited surface area for access to the investigated object.

The aim of present work is the comparison of various methods of 2D OA imaging under condition of single-side access to the object and various types of acoustical receivers. The necessity of such modeling is determined by the fact that unlike active ultrasonic location the acoustical circuitry of OA scanner operates only in receiving mode and some difficulties related with contrast can occur.

To use scanner in clinical conditions it is necessary to provide the acceptable rate of image generation. The time required to generate one frame of tomogram is determined by the expression: $T = N_{row} T_{row} N_{acc} / N_{ch}$, where N_{row} is the required number of frame rows (or number of directions for angular scanning), T_{row} is time of one row acquisition ($T_{row} = 1 / F_p$, where F_p is pulse repetition rate for source), N_{acc} is coefficient of signal accumulation applied to improve signal-to-noise ratio, N_{ch} is a number of parallel channels of signal receiving.

For the transducer with mechanical sector scanning $N_{ch}=1$, thus paralleling of receiving channels is impossible and frame generation time is determined by pulse repetition rate of heating radiation source and is limited below by propagation time of acoustical waves in the investigated area. It is evident that increasing image generation rate is possible only in the case of parallel receiving of OA signals by several receivers. Estimated potential speed for various scanning types is shown in table. The laser with $F_p=10$ Hz is considered as a source, $N_{acc}=10$. The number of receiving channels for electronic scanner is chosen $N_{ch}=8$, providing parallel signal digitizing with acceptable quality (applying ADC with large number of channels either causes decay of signal-to-noise ratio or jump in cost of scanner hardware).

Scanning method	Number of channels	Number of image rows	Frames per minute
Механическое секторное сканирование	1	60-90	0.67-1
Linear electronic scanning	8	32-64	7.5-15
Sector electronic scanning	8	16-24	15-30

A model of acoustically homogeneous medium containing optically absorbing spherical ‘defects’ 2 mm in radii each placed at 20, 30 and 40 mm depth (Fig. 1) was chosen for simulation of receiving and reconstruction of OA signals. Center of the receiving antenna is positioned at (0, 0). The solution of equation of OA wave generation can be written analytically [13]. The influence of medium boundaries and acoustical absorption is taken into account by adding reflected signals and damping into obtained solution. Besides that the finite receiving bandwidth of ultrasonic transducer was also considered. The solution of direct problem for spherical object is well known – it is N-shape pulse with duration determined by sound travel time through sphere diameter and duration of edges determined by pulse duration of heating radiation (see, e.g. [2, 13]). The pressure wave falling on the transducer is integrated over aperture of the receiving antenna and is converted into electrical signal. This signal is the response of narrow-band system to the sharp-edge signal, and it can be evidently seen that in real conditions of receiving by quasi-resonant transducer of MHz range only boundaries of heterogeneity can be selected if its characteristic dimensions are about several millimeters [3]. After that the reconstruction of OA image is performed by one of possible algorithms; here we interpret OA image not as reconstruction of spatial distribution of absorption but localization of boundaries of absorbing areas (similarly to the traditional clinical echography [14]). Reconstructed tomogram is presented in the form of 2D image.

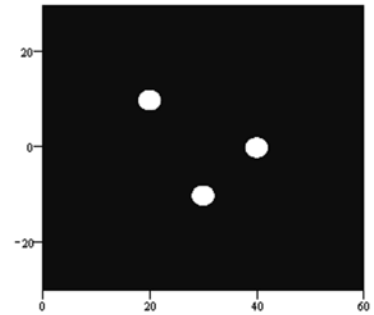


Fig. 1

Earlier we implemented the experiments [11, 12] with the aim of studying of applicability of weakly focused acoustical transducers with angular mechanical scanning (similar to those useful in USI) for deep OA tomography. The 2D OA tomograms of model objects with injected optical heterogeneities were obtained. It was demonstrated that sensitivity of used acoustical receiver is sufficient to detect weakly contrast optical heterogeneities (contrast coefficient as low as 0.6 for gelatin phantom) having indistinguishable acoustical properties from surrounding medium [9]. Low transversal spatial resolution (5-7 mm) is explained by use of standard ultrasonic transducer (SCAD 9210) intended for echocardiographic and abdominal applications. This transducer has focal waist at 70-90 mm depth while operating depth range in our experiments on OA tomography haven't exceed 50 mm.

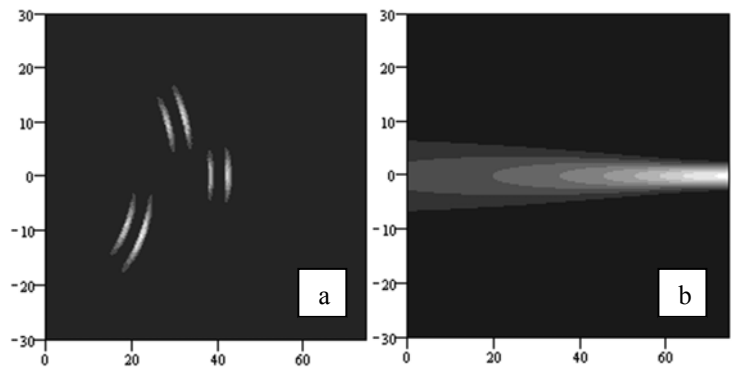


Fig. 2

To compare theory with experiment we carried out the numerical simulation of OA signal receiving by weakly focused single-element transducer similar to that one we used in these experiments. Sensitivity spatial distribution can be approximated by Gaussian function for this receiver [16]. The results of reconstruction (a) and spatial distribution of transducer sensitivity (b) are shown for two values of focal depth – 80 mm (Fig. 2) and 40 mm (Fig. 3). The calculated images for the first case are close to our experimental results [11]. It is also possible to improve the transversal resolution in the case of mechanical receiver by use of short-focus receiver with focusing into the zone of OA receiving (20-40 mm), but usually such receivers operate at high-

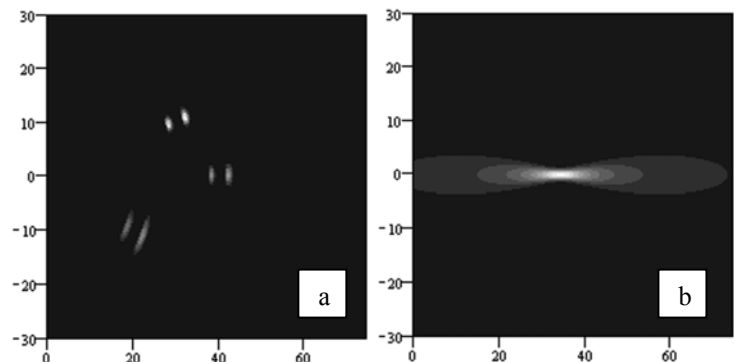


Fig. 3

er frequencies (7-10 MHz), being disadvantageous for deep OA tomography of large-scale heterogeneities as we demonstrated earlier [3].

Fig. 4 shows the results of numerical simulation of OA signal receiving and image reconstruction at linear electronic scanning. The linear array consists of 30 elements 2 mm size each in scanning plane. The results presented correspond to the version of signal processing by their summation with the delays forming converging wave front focused at 30 mm. The compensation of sensitivity in the form of linear time function was also applied for magnitude equalizing of signals coming from various depths.

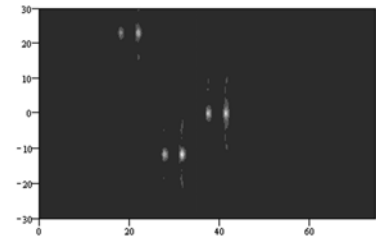


Fig. 4

Fig.5 shows the results of simulation for an array consisting of 60 elements 1 mm each. Processing was made by summation over 10 neighboring elements with the delays corresponding to 'axicone' focusing, i.e. delay of signal linearly increases from group center to the periphery. It is known that such focusing provides formation of lengthy focal waist [15]. It can be seen from this figure that such an array provides both satisfactory transversal resolution and the simplicity of technical requirements to the transducer manufacturing.

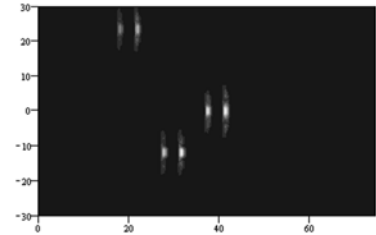


Fig. 5

Then we considered the problem of OA reconstruction with use of multi-element transducer realizing angular electronic scanning. The advantages of such antenna are the reduced number of receivers and thus the reduced number of digitizing channels, and also smaller area of contact between transducer and medium surface. The necessary number of receiving elements can be estimated from simple considerations: ratio of magnitude of sum of phased pulses to the magnitude of non-phased pulses has an order of N (note that this ratio has an order of N^2 for active locator) [8]. This ratio determines the dynamic range of the receiving. Increasing number of elements above 20-30 is not advantageous evidently, because dynamic range grows slowly at the expense of technical complication. Angular electronic scanning is provided by summation of delayed electrical signals generated by antenna elements [15].

The 21-element receiving antenna consisting of ultrasonic receivers with 0.3 mm size along the antenna and 0.5 mm distance between element centers was chosen for simulation, thus the entire antenna dimension along scanning plane is 10 mm. Scanning was performed in angle range 90° with focusing in the center of depth range i.e. 30 mm. Fig. 6 shows the results of simulated reconstruction of the same object. Selecting focal length for various zones of signal receiving evidently allows to improve significantly the transversal resolution at satisfactory longitudinal one.

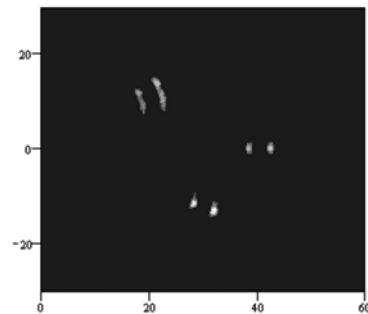


Fig. 6

Hence the scheme with mechanical sector scanning differing from other ones by relatively simple hardware and algorithm of image construction can be used only in the conditions where time of scanning and reconstruction is not a critical parameter, e.g. for investigation of quasi-static objects in laboratory at limited access to the object surface. Application of linear arrays (see e.g. [17]) allowing parallel multi-channel data acquisition seem to be more attractive for clinical use of deep OA tomography because it allows to reduce significantly acquisition time and to use more robust algorithms of tomogram reconstruction based on aims of investigation.

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