Far Eastern Mathematical Journal. 2022. V. 22. No 2. P. 255–256

UDC 519.6
MSC2020 68T07, 74J25

© A. V. Vasyukov[1], A. S. Stankevich[1], K. A. Beklemysheva[1], I. B. Petrov[1]

Using 2D/3D convolutional neural networks and direct numerical modeling for transcranial ultrasound problems

The paper considers the problems of modeling diagnostic medical ultrasound in relation to the study of cerebral vessels through the skull wall. The bone tissue of the skull wall distorts the wave fronts, creating artifacts and aberrations in the image. The report presents mathematical models and numerical methods for solving a direct problem - calculating a numerical ultrasound image (B-scan). The models and methods cover an acoustically homogeneous medium, reflecting boundaries between different tissues, individual bright point reflectors. The report also presents the results of solving the inverse problem — restoring the real configuration of the media under investigation based on ultrasonic data. 2D and 3D convolutional neural networks are used for the inverse problem.

Key words: *ultrasound, numerical modeling, inverse problem, convolutional neural networks.*

DOI: https://doi.org/10.47910/FEMJ202235

The work demonstrates that direct numerical modeling can be used to obtain synthetic numerical ultrasound images of high quality. The present study considers elastic waves propagation in the media, as well as their reflection and refraction on the boundaries between the media with different rheological parameters. The modeling covers the reflection from relatively large acoustically contrast objects and the presence of a background noise caused by a large number of weak point reflectors. The combination of these effects allows to reproduce real ultrasonic images with good accuracy. Synthetic numerical data can be used to study the capabilities of sensors for complex cases. It can also be used for the development of neural networks if real experimental data is limited.

The work considers an inverse problem of determining a position and shape of a silicone prism acting as an aberrator during an ultrasound scanning. The problem statement assumes the presence of strong random noise and significant signal distortions caused by the complex shape of the aberrator and its inhomogeneity. The paper demonstrates that

[1] Moscow Institute of Physics and Technology (National Research University), Russia, 141701, Dolgoprudny, Moscow Region, Institutskiy per., 9.
E-mail: `a.vasyukov@phystech.edu` (A. V. Vasyukov).

a convolutional neural network can effectively determine the position of the boundary between the aberrator and the bulk of the material. The network works correctly in the case when responses from individual large reflectors exist that are comparable in brightness to the response from the boundary. This capability of the network is due to its 3D architecture which allows full use of the information from all spatial directions.

It should be noted that all the results of the present work regarding the inverse problem were obtained using an acoustic approximation. The use of this model is appropriate for a large number of important cases since in soft biological tissues shear waves attenuate at a distance of a few millimeters when using a typical medical ultrasound frequency range. Another reason is that B-scan reconstruction algorithms effectively suppress all the waves except longitudinal ones. However, the future work should cover the transition from acoustical model to full elasticity model. It is also important to consider the boundary between elastic media (bone tissues) and acoustical media (soft tissues).

Received by the editors
October 2, 2022

The research was supported by the Russian Science Foundation (Project No. 22-11-00142).

Васюков А. В., Станкевич А. С., Беклемышева К. А., Петров И. Б. Использование 2D/3D свёрточных нейронных сетей и прямого численного моделирования для задач транскраниального УЗИ. *Дальневосточный математический журнал.* 2022. Т. 22. № 2. С. 255–256.

АННОТАЦИЯ

В работе рассматриваются задачи моделирования диагностического медицинского ультразвука применительно к исследованию сосудов головного мозга через стенку черепа. Костная ткань стенки черепа искажает волновые фронты, создавая артефакты и аберрации на изображении. Описываются математические модели и численные методы для решения прямой задачи — расчёта формирования изображения (B-скана) для акустически однородной среды, для расположенных в ней отражающих границ, для отдельных ярких отражателей. Приводятся результаты решения обратной задачи — восстановление реальной конфигурации среды на основании исключительно данных с ультразвукового датчика. Для обратной задачи используются 2D и 3D свёрточные нейронные сети.

Ключевые слова: *ультразвук, численное моделирование, обратная задача, свёрточные нейронные сети.*