THE SIMULATION OF PROPAGATION OF ULTRASOUND DURING INVASIVE AND NONINVASIVE NEUROSURGICAL TREATMENTS

Marjan Sikora*, Bojan Ivančević**, Kristian Jambrošić**

*Sv. Klare 14, HR-21000 Split, Croatia, E-mail: marjan.sikora@st.hinet.hr
**Faculty of Electrical Engineering and Computing, Unska 3, HR-10000 Zagreb, Croatia,
E-mail: bojan.ivancevic@fer.hr, kristian.jambrosic@fer.hr

Abstract: **Neurosurgical treatments of brain tumours can result with damage to healthy tissue. In order to avoid this the 3D computer simulation was developed. The measurements were carried out on real scull, in order to check the simulation. To improve accuracy of the simulation beside the specular reflections, the diffuse reflections were added to the model. The results of the simulation indicated the endangered healthy areas of the brain.**
In addition, computer simulation is being developed for non-invasive neurosurgical treatment with focused transducer array.

Keywords: **ultrasound, computer simulation, neurosurgery**

Introduction

Neurosurgery treatment of brain tumours using ultrasound cavitation aspirators (CUSA) often result with damage of healthy tissue. Due to characteristic shape of human scull, several parts of the brain are endangered. To locate the endangered parts the computer simulation was used, as a tool to help surgeon. With the help of the simulation, the surgeon can identify the risk and make the necessary adjustments to surgical treatment in order to minimize unwanted damage to healthy tissue [1].

Focusing the ultrasound energy to a single spot in the brain, without opening the scull is very complex. The array of ultrasound transducers located on the skin of the head, produces ultrasound waves that propagate through several discontinuities. The computer simulation of propagation of ultrasound waves from outside the scull to the focus spot in the brain is being developed in order to check the possibilities of such a treatment. The simulation would also help to define the construction of ultrasound transducers that would be used for treatment.

Materials and Methods

For the purpose of simulation of propagation of ultrasound during neurosurgical treatments with CUSA, the computer simulation based on the virtual source model was used [2,3]. The simulation takes into account the propagation of the sound inside the medium (brain), and the reflections of the ultrasound from the scull. It calculates the changes of amplitude and phase of sound during propagation and reflection and sums the direct sound and all reflected sounds in order to obtain the sound pressure level distribution in brain. The sound pressure distribution is calculated in the form of slices with predefined resolution.

In order to check the accuracy of the simulation, the measurements were carried out. On the real scull, the sound was measured in 9 points [4, 5].

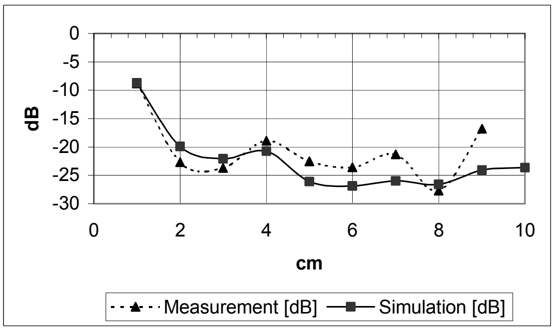
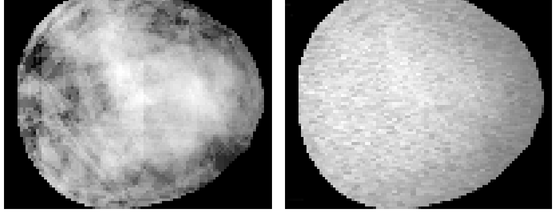


Figure 1: Comparison between measured and simulated values of SPL

The expected accuracy was 3 dB (Figure 1). This level of accuracy, although satisfactory for experiment purposes, needed to be improved for use in real life. The lower part of the human scull has very irregular shape. This results in the strong diffuse reflections, which were not taken into account in the basic model. Since virtual source model calculates only specular reflections, diffuse reflections are calculated with stohastical method [6], and the amount of energy that is diffused is defined by a diffusion coefficient (Figure 2).

Figure 2: Simulation without (left), and with diffusive reflections (right)



Simulation is also used during the process of focusing of ultrasound energy from the array of ultrasound transducers located on the skin of the human head. It calculates the attenuation and reflection of ultrasound on the protective layers in human head (skin, scull, dura mater, pia mater, arachnoid), and the diffraction of the path of propagation of the ultrasound. To take into account these phenomena the different mathematical model would be used. The refraction of sound causes the focusing of the ultrasound energy. Therefore, the choice had to be made between ray-tracing, cone-tracing and pyramid-tracing models. To avoid problems with aliasing and to be able to accurately calculate the focused energy the pyramid-tracing model was chosen [7].

Results

The simulation was done for real human scull. The CT scan of the patient scull was digitised, and transformed into TIN (triangulated irregular network) grid (Figure 3).

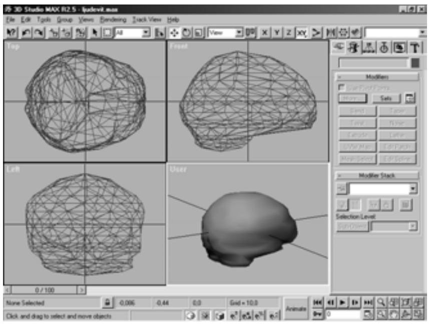


Figure 3: The TIN grid of the human scull

The acoustical parameters of the simulation were: the velocity of sound 1528 m/s [8, 9], the absorption of the brain tissue 0.44 dB/cm [10], and the frequency of the ultrasound 24,5 kHz.

The simulation indicated that during the surgical treatments of brain tumours the undesirably high level of ultrasound energy occurs in the central part of temporal lobe. This can cause the damage to healthy tissue of speech, motor and sensory functions (Figure 4).

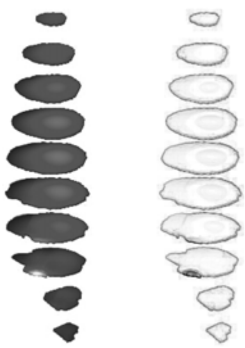


Figure 4: The results of the simulation: the tumour is in the lower part of the left hemisphere of the scull

Conclusions

The computer simulation can be of great help during the neurosurgical operations with CUSA. It can help to reduce the risk of damaging the healthy tissue during the cavitation process. This is achieved by carefully planning the path of approach during the surgery, and by calculating the right level of applied ultrasound energy, which is enough to destroy the tumour, and below the level, which would cause the damage to healthy tissue.

With several other phenomena taken into account the simulation can be well used in the process of the design and application of focused transducer array that can without the invasion of the scull transfer the ultrasound energy to the right spot in the brain. Using such array, the damages made to patients scull, and healthy tissue inside the brain could be minimized.

REFERENCES

[1] Richard A. Robb, Jon J. Camp, Dennis P. Hanson, Computer Aided Surgery and Treatment Planning at the Mayo Clinic, http://www.mayo.edu/bir/reprints/CAS.html

[2] M. Sikora, Magistarski rad, Zagreb, 2000.

[3] M. Keliner, B.I. Dalenback, P. Svensson, Auralization-An Overview, *J. Audio Eng. Soc.*, Vol. 41, No. 11

[4] B. Ivančević, I. Zorić, M. Sikora, Computer simulation and measurement of the ultrasound field in a bounded plane, *IMEKO TC-4 Symposium on Development in Digital Measureing Instrumentation*, Napulj, 1998.

[5] B. Ivančević, , I. Zorić, M. Sikora, Sound field measurement in the bounded plane, *Procc. ELMAR*, Zadar, 1997.

[6] M. Sikora, H. Domitrović, CODA-COmputerized Auralisation, *100th AES Convention, Kopenhagen*, 1996.

[7] A. Farina, Validation of the scattered sound field with a geometrical pyramid tracing approach, ACOUSTICS 2000 - IOA Conference, Liverpool (GB) 17-18 April 2000.

[8] I. Zorić, Doktorska disertacija, Zagreb, 1997.

[9] I. Zorić, B. Ivančević, K. Jambrošić, The velocity of Ultrasound propagation through brain tissue at low ultrasound frequencies, *25th German Acoustics DAGA Conference*, Berlin, 1999.

[10] I. Zorić, B. Ivančević, H. Domitrović, Measurement of brain tissue attenuation by the TDS method, *Proceedings of 8th International IMEKO Conference on Measurement in Clinical Medicine*, Dubrovnik, 1998., 9-9 – 9-12.