Gynecologic electrical impedance tomograph

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Abstract. Electrical impedance tomography extends to the new and new areas of the medical diagnostics: lungs, breast, prostate, etc. The feedback from the doctors who use our breast EIT diagnostic system has induced us to develop the 3D electrical impedance imaging device for diagnostics of the cervix of the uterus - gynecologic impedance tomograph (GIT). The device uses the same measuring approach as the breast imaging system: 2D flat array of the electrodes arranged on the probe with handle is placed against the body. Each of the 32 electrodes of the array is connected in turn to the current source while the rest electrodes acquire the potentials on the surface. The current flows through the electrode of the array and returns through the remote electrode placed on the patient's limb. The voltages are measured relative to another remote electrode. The 3D backprojection along equipotential surfaces is used to reconstruct conductivity distribution up to approximately 1 cm in depth. Small number of electrodes enables us to implement real time imaging with a few frames per sec. rate. The device is under initial testing and evaluation of the imaging capabilities and suitability of usage.

1. Introduction
The cervix cancer is the second cancer by frequency at women after the breast cancer. In view of absence of any clinical picture of the disease predecessors, the problem of early detection of this pathology is topical. Carrying out the screening which allows suspecting the disease conditions is necessary because of this. The requirements to the screening procedure are: availability, low cost, informativity (sensitivity should be 60 - 75 % at least), revealing of disease at early stage (preinvasive cancer). Currently there is a set of methods for diagnostics of cervix diseases including biopsy, echography, MRI and so on, but besides the set of advantages, there is a number of the drawbacks limiting usage of these methods for screening examinations.

The feedback from the doctors who use our breast EIT diagnostic system [1 - 3] has induced us to develop the 3D electrical impedance imaging device for diagnostics of the cervix of the uterus - gynecologic impedance tomograph (GIT). The developed device allows not only to estimate visually vaginal part of cervix of the uterus, but also to obtain parameters of its electrical conductivity at depth of almost 1 cm thus revealing pathological changes in epithelium without invasive and operative interventions. In addition the EIT method will probably enable to investigate features of electrical conductivity during background diseases of the cervix.

The electrical impedance tomography of the cervix of the uterus meets all screening method requirements for diagnostics of precancer diseases: it is simple, accessible, noninvasive, it has no restrictions for the frequency of procedure repetition, does not require special preparation of the
patient, allows to detect pathological changes in cervix at depth up to 1 cm without surgical intervention, it is informative and painless. Safety of the method allows using it during pregnancy and also at young nonparous women for whom carrying out biopsy is undesirable.

2. Materials and methods
The GIT device uses a method of electrical impedance tomography. It consists of the measuring unit with the built-in microcontroller system, scanning head with 32 electrodes arranged in flat 2D array, see figure 1, and a dual auxiliary electrode connected to the main unit. During investigation the device injects alternating electric current into the body of patient by means of each single electrode of the head sequentially and measures corresponding distributions of electric potentials by means of the rest electrodes.

![Figure 1. Measuring head of the tomograph with array of 32 electrodes. Diameter of the wide part of the head is 3 cm.](image)

The tetrapolar measurement approach is used: the current is injected through the single electrode of the array and first auxiliary electrode placed on the patient’s wrist. The voltage distribution is measured relative to second auxiliary electrode. All possible combinations of injecting and receiving electrodes are used. The redundant data caused by reciprocity are used to improve accuracy of measurements. Received data are used then for solving inverse problem and showing on the PC screen of the electrical impedance tomograms of tissues under investigation by means of the reconstruction algorithm implemented on the personal computer. The measuring unit is connected with PC through USB connection, which provides power supply also. The software provides functions for the analysis, comparison and archiving of the results of measurements and reconstruction. Carrying out of dynamic repeated investigations with the purpose of revealing of the processes dynamics is possible. Use of multifrequency sounding allows GIT device to obtain the additional information on a condition of tissues, considerably raising informative value of the examinations.

The block-diagram of the measuring system is shown on figure 2. The low level hardware functions are controlled by the embedded microcontroller. Both generation of output and demodulation of input signals are carried out digitally. The embedded software and periphery enable measuring and compensation of residual galvanic voltages, detection of bad contacts of the electrodes with the object and self-testing of the whole measuring chain. Important difference between the GIT device and its prototype, the EIT system for breast imaging, is usage of active shields in the cables connecting electrodes of the head with the main measuring unit. Without such shielding, stray penetration of the signals between channels in 1-meter connecting cable may add artifacts in the reconstructed images. The measuring system can be programmatically configured to make measurements at any frequency between 1 and 50 kHz.
The image reconstruction is carried out using 3D weighted back projections along electric field equipotential surfaces. The reconstruction formula and weighting factors are the same as for breast imaging device [2]:

\[
S(x,y,z) = 1 + W_1(z) \sum_i \frac{1}{\int_{L(x,y,i)} W_2(l) \, dl} \int_{L(x,y,i)} W_2(l)(E_r(l) - E_m(l))/E_r(l) \, dl,
\]

where \(S(x,y,z)\) is reconstructed conductivity, \(E_m\) and \(E_r\) are the measured and synthesized reference electric intensities at the surface of the object, \(W_1\) is monotone increasing weight function, which equalizes sensitivity in depth \(z\), \(W_2 = 1/R^4 = 1/\left((x-x_i)^2 + (y-y_i)^2 + z^2\right)^2\), \(i\) is the number of the injecting electrode, and \(L(x,y,i)\) is the line of intersection of the equipotential surface with the plane \(z=0\), on which the electrodes are arranged.

The significant difference between the two systems is number of the electrodes in array: 256 in case of breast imaging device and only 32 for the gynecological tomography system. This makes real time imaging possible in the GIT device but limits quality of the images. To make 3D data readable on the 2D PC screen the reconstructed conductivity distributions are represented as set of three 2D slices with increasing depth.

3. Results
The measuring system is under preliminary clinical tests now [4]. Due to relatively small number of electrodes the device can provide near real time visualization with a few frames measured and reconstructed per second. The small number of electrodes provides images with quite poor resolution, see example on the figure 3. Nevertheless, high correlation between electrical properties of the tissues and their physiological state and conditions and relatively simple anatomy of the object under investigation makes such images usable for diagnostics. First tests have shown that cable connecting measuring head with the main unit may cause artifacts on the reconstructed images due to spurious coupling between channels if the wires are not shielded. This effect is strong for the objects with high impedance (skin resistance), when imaging hand, for example. But low impedance mucous membrane of the cervix makes its influence insignificant. Nevertheless using of active shields in the cable seems strongly desirable.
4. Conclusions
The first electrical impedance imaging system for examination of the cervix of the uterus has been
developed. The device provides 3D EIT images of the conductivity distribution in a few cross-sections
with depth up to 8 mm and with more than 1 frame per second measurement and reconstruction rate.
The cervix cross-section anatomy is visible on the images. Further development should include
optimization of the measuring head for convenient application and sterilization. The device should be
designed as self-contained and independent on external PC, to be approved for most clinical scenarios
of usage.

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