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Chest Impedance Imaging Using Trigonometric Current Patterns

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1. Introduction

OXBACT-III is a 32-channel Electrical Impedance Tomograph. It was designed for real-time acquisition of 32 voltage measurements while a set of 32 currents was applied. The currents are programmable, allowing the application of trigonometric or adaptive patterns. Real-time is defined as being fast enough to acquire a full measurement set while the physiology of the subject remains essentially constant. For the first trials the maximum frame-rate was 10 per second, which does not meet the "real-time" criterion. Code and procedural optimisation should lead to a frame-rate of 25 per second in the near future.

The results of the first two experiments with the system applied to a subject — rather than a phantom — are presented in this paper. In the first experiment single measurements were made during breath-holding at a) forced expiration, b) near FRC, and c) maximal inspiration. These images, and a difference image formed by subtracting image (a) from image (c), are presented. In the second experiment sets of 32 successive frames were obtained at a rate of 10 frames per second. The reconstruction of the images was carried out off-line. The resulting images can be viewed as a sequence on a PC at a rate of 10 per second to emulate real-time. Measurement sets were acquired during breath-holding at different lung volumes and also during a continuous inspiration which spanned the 3.2 seconds.

2. Experimental Protocol

The data-acquisition section of OXBACT-III was programmed to apply the first 20 trigonometric current patterns to a set of 32 electrodes. The 32 voltage measurements made during each of the current patterns formed a single measurement set from which one image was reconstructed. This process could be run in 100 ms. The excitation frequency for all measurements was 40 kHz, and the maximum current that was applied to any electrode was 1 mA.

The current electrodes were applied to prepared skin in a plane approximately 3 cms below the level of the nipples - the electrodes on the back were therefore just below the lower edge of the scapulae. Skin preparation was achieved by wrapping adhesive tape (Sellotape) around the chest where the electrodes were to be placed. The tape was removed and the skin surface wiped with alcohol-soaked swabs. Standard ECG electrodes were used (ARBO H157 Ag/AgCl , pad size 22mm x 35mm; the pads were trimmed to a point at one end). The electrodes were applied first to the anterior and posterior midline, then by measurement to halfway between, successively, until there

were 32. The pointed ends of the pads were at the bottom. A second set of 32 electrodes was then applied - with the pointed ends upwards - so that the active part of the electrodes were in a line approximately 2.5 cms below the line of current electrodes. These voltage measurement electrodes were close to midway between the current electrodes; the points facilitated the positioning.

The subject sat during the data acquisition. In the first experiment single sets of measurements were made. In the second experiment a number of 32-frame measurement sets were taken. The subject found it difficult to lower his heart-rate below 100 beats per minute, so only 6 images could be acquired during each cardiac cycle. Sets of images were acquired in 3.2 seconds, during which either breath-holding at some lung volume was maintained, or a full inspiration was made.

The reconstruction programme takes longer than 100ms to run, so the image reconstruction from the measurement data sets was carried out off-line. The reconstruction was performed on a Digital Alpha work-station (DEC 3000) and the images displayed on a PC. The images were saved as bitmaps and loaded into a display program (Autodesk Animator) which re-displayed them at the original acquisition rate of 10 per second.

3. Data Acquisition

OXBACT-III has a multiprocessor system architecture. A TMS320C40 processor is used to control the data acquisition system (DAS), an i860 vector processor is the core of the image reconstructor, an i486 host PC is responsible for user interface and image displaying. A T805 transputer is employed to accomplish data communication between DAS and reconstructor.

The DAS operates at several frequencies from 10kHz to 160 kHz. It applies currents simultaneously through 32 electrodes using voltage controlled current generators, and uses multiplexers to select one of 32 voltage electrodes at a time for measurement by an ADC. The order in which the multiplexer is switched between voltage channels and the timing of the ADC are controlled by a RAM and hence these may be easily reprogrammed for any number of different configurations. A calibration sub-system (Denyer et al) was designed and used to measure load current and ensure accuracy of voltage measurement. The data acquisition and calibration are fully controlled by the TMS320C40 processor which also accomplishes digital demodulation.

High speed ADC, video speed multiplexers and a non-uniform over-sampling technique (Zhu et al) are employed to improve signal noise ratio and ensure high speed imaging. For each applied current pattern, a total of 8K voltage measurements (32 channels x 256 samples per channel) can be collected in just 2ms. The frame rate of 20 images per second can easily be realised if only 10 current patterns are applied for each image frame.

4. Reconstruction and Display

The reconstruction method used was a regularized Gauss-Newton method described in Breckon (1990) and Paulson (1993) and revered to as RECON in Paulson et al (1995). For each image only the first iteration was performed starting from a uniform background conductivity. The reconstruction was therefore actually a linear method. The data were the measurement set described above in section 2. The forward model was a two dimensional circular finite element model of 761 nodes and 1264 linear triangular elements. The conductivity was represented on a 93 node finite element mesh of 152 linear triangular elements.

5. Results and Interpretation

Here go the pictures. We have to agree what we can see. It wont be as convincing without a movie so we will have to connect with cardiac and respiration. We also have to agree what we can see. Contribute your ideas please.

6. Future Work

This initial in vivo study using the OXBACT III system has not yet used some of its more important features. In particular only trigonometric rather than adaptive current patterns were used. Further iterations with adjustment of the Tikhonov factor could well improve the image. Also the faster POMPUS reconstruction algorithm has not been tried on this data. The integrated reconstruction and data acquisition system using the i860 processor was not ready when this study was carried out but we anticipate using that system on *in vivo* data in the near future. We also plan to experiment with more realistic boundary shapes for the forward model and to employ electrode belts for more accurate electrode positioning.

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