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ELECTRICAL IMPEDANCE TOMOGRAPHY FOR HIGH SPEED CHEST IMAGING

W.R.B. Lionheart F.J. Lidgey, C.N. McLeod, K.S. Paulson, M.K. Pidcock, Y. Shi,

EIT Research Group, School of Engineering & School of Computing and Mathematical Sciences, Oxford Brookes University, Gipsy Lane Campus, Oxford OX3 0BP, U.K.

1. Introduction

Electrical Impedance Tomography (EIT) is a method for imaging the internal conductivity distribution of a cross section of human body using known injected currents and measured potentials on the surface. The problem of recovering the internal conductivity from this data is extremely ill-conditioned and, by contrast to many other medical imaging techniques, non-linear. Inevitably EIT images will be low in spatial resolution but the technique promises high temporal resolution, continuous monitoring, relatively low cost and the possibility that soft tissue changes may be imaged which are invisible to other imaging techniques.

2. OXBACT III system

OXBACT (Oxford Brookes Adaptive Current Tomograph) Mark III is the third generation EIT system developed in Oxford for *in vivo* clinical studies. It applies current simultaneously through 32 current electrodes and measures voltages on the 32 voltage electrodes, in a frequency range from 10kHz to 160kHz. Zhu *et al* [1] and Denyer *et al* [2] give further details of the instrumentation.

The system has three main components. The Data Acquisition System (DAS) performs the current setting and voltage measurement. A digital signal processor (Texas Instruments TMS320C40) controls the current sources and demodulates the measured data, it also performs system calibration and data communication. The Interactive Tomograph Controller (ITC) consists of an i486 PC host running a control and display program with a graphical user interface. This host PC is connected to the DAS by a fibre optic link, and on its ISA bus has an Intel i860 vector processor which serves as the Image Reconstruction Unit (IRU). This performs the forward modelling and image reconstruction. Thanks to this multiprocessor architecture, pipelined data flow can be easily implemented in OXBACT III for real time imaging, with the DAS carrying out data acquisition for image frame T(i), the IRU reconstructing image frame T(i-1) and the ITC displaying image frame T(i-2). The synchronisation is carried out by a system clock. The high performance of TMS320C40 makes it possible for the DAS to achieve a frame rate of 25 images per second. The IRU and ITC have not yet been optimised to achieve this speed.

The reconstruction method used was a regularised Gauss-Newton method described in Breckon [3] and Paulson [4] and referred to as RECON in Paulson et al [5]. The forward model was a two dimensional elliptical finite element (FE) 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. The largest inaccuracies in our finite element model when used to represent a cross section of the human chest are that the body is inherently three dimensional and that it is not elliptical in cross section. For each image only the first iteration was

performed starting from a uniform background conductivity. The reconstruction was therefore actually a linear method. Experience with circular tanks indicate that when the boundary shape is known more accurately up to seven iterations can improve image quality. Work on a more accurate body shape in our FE model is underway as are automatic methods of shape measurement [6]. The effect on the chest shape changes during respiration has been studied by Adler *et al* [7].

In contrast to relative EIT imaging systems such as the Sheffield APT system [8] which aim to produce only an image of conductivity change, this system is designed to determine absolute conductivity values. This is a more difficult task due to the non-linearity of the problem. OXBACT III has, in common with the ACT 3 system at Rensselaer [9], the ability to apply current patterns on a system of drive electrodes rather than simple pair drives. In contrast to ACT 3 however the system makes measurements on a separate system of electrodes from those used to drive current.

5. *In-vivo* chest impedance imaging

The goal of our tests was to image the lung function and cardiac function of the subjects. Data acquisition was done at a rate of about 25 images per second. The image reconstruction was carried out off-line. The excitation frequency for all measurements was 40 kHz, and the maximum current that was applied to any electrode was 1 mA. The trigonometrical current patterns were used in the tests. Only 12 out of 31 independent current patterns ($\sin(kx)$ with k=1,2,...,6 and $\cos(kx)$ with k=1,2,...,6), were used, based on the trade-off between image rate and signal to noise ratio.

In order to understand the information supplied by the images of lung and cardiac functions, two analogue signals were taken by the DAS from the subject. One signal came from a Respitrace monitor (Studley Data Systems, Oxford), recording the change of thoracic volume during respiration of the subject the other came from a Finapres monitor (Ohmeda), supplying information about blood pressure change.

The 32 current electrodes and 32 voltage electrodes of the DAS, along with the transducers for Respitrace and the ECG, were applied to the thorax of the subject after careful skin preparation. The cuff of the Finapres was applied to one finger of the subject. The subject sat upright on a stool, keeping the Finapres transducer at approximately heart level.

In the first test, data for 128 successive images were taken during about 4.5 second, in which the subject accomplished 2 or 3 respiration cycles. In the second test, another data set of 128 successive images was taken during about 4.5 second, in which the subject held his breath at some lung volume.

The 128 images of each test were then saved as bitmaps and loaded into a display program (Autodesk Animator) which re-displayed them at the original acquisition rate [1]

6. Results and Analysis

Each of the *in vivo* images shows two low conductivity regions which correspond to the two lungs of the subject, and a high conductivity central region which should include the heart and main blood vessels of the subject.

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[1] An animation of these chest images is available on the World Wide Web at the locator http://www.brookes.ac.uk/~p0054865.

The image sequence from the first test clearly shows the change of conductivity in the two lung regions during respiration cycles (Fig 1). When the conductivity change of representative pixels from each lung are plotted against the data obtained from the Respitrace, they matched each other in time perfectly (Fig 2(a)). Cardiac function resulting in conductivity change in the central region on the images can also be seen and the relation with the Finapres signal can be seen in Fig 2(b). The shape and size of the lung regions is inaccurate, and the spine is absent. The phase relationship between the cardiac synchronous conductivity changes in the chest and those in the Finapres could be explained by pulse travel times, but independent verification of the signals is not currently possible.

7. Conclusion and future work

The preliminary *in vivo* results show that OXBACT III has a high precision data acquisition system due to the use high speed ADC, DSP sampling patterns and its novel calibration system. The first high speed *in vivo* images showing lung ventilation and cardiac function of subjects are encouraging. We have achieved some spatial localisation of the measured impedance signal and believe the system will yield useful physiological information.

Future work will involve more *in vivo* trials and clinical trails, applying adaptive current patterns, using accurate and known electrode placement, real time imaging, imaging at two other frequencies, use of imaginary part of admittance at high frequencies and use of a mesh boundary shape which matches the thorax.

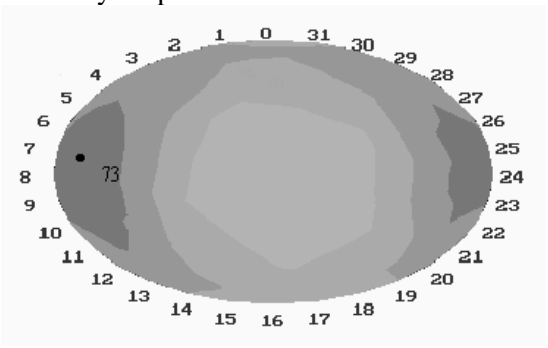

Figure 1(a). Early inspiration (Node 73 indicated)

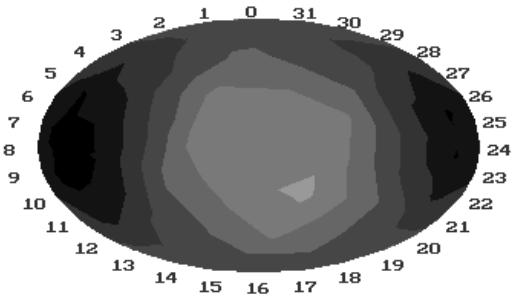

Figure 1(b). Late inspiration

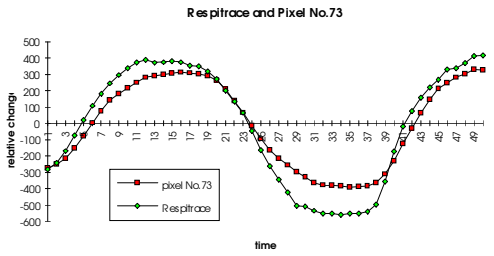

Figure 2(a). Relative conductivity decrease and Chest Volume

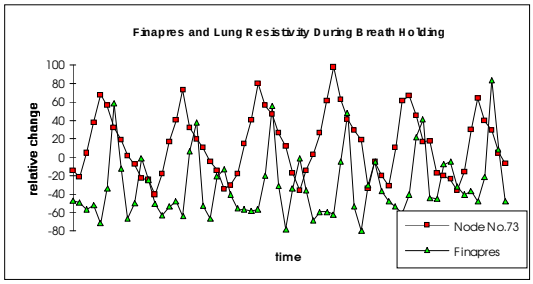

Figure 2(b). Conductivity and Blood Pressure.

Acknowledgements

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