Chapter 9

Electrical Impedance Tomography

9.1 Introduction

Electrical impedance tomography (EIT) uses low-frequency electrical current to probe a body; the method is sensitive to changes in electrical conductivity. By injecting known amounts of current and measuring the resulting electrical potential field at points on the boundary of the body, it is possible to "invert" such data to determine the conductivity or resistivity of the region of the body probed by the currents. This method can also be used in principle to image changes in dielectric constant at higher frequencies, which is why the method is often called "impedance" tomography rather than "conductivity" or "resistivity" tomography. However, the aspect of the method that is most fully developed to date is the imaging of conductivity/resistivity. While EIT methods have not yet gained a significant foothold in the medical imaging community, they have been shown to work well in both geophysical and industrial settings and, therefore, it is possible that future medical imaging applications may follow rather rapidly from the advances made for other applications.

9.2 Comparison to Other Modalities

There is a formal mathematical analogy between EIT and x-ray computed tomography (CT), since in either case data must be processed to produce the desired image of interior structure and, furthermore, the imaging is often performed on two-dimensional slices through the body. EIT uses diffusion of current to deduce conductivity distribution, unlike methods such as magnetic resonance imaging (MRI), CT, positron emission tomography (PET), and single photon emission computed tomography (SPECT).

EIT is expected to have relatively poor resolution compared to MRI, CT, PET, and SPECT. Resolution is largely controlled by the number of electrodes that can be reasonably attached simultaneously to a patient. Schemes used to date have normally used electroencephalogram-style electrodes, relatively few in number and large in size. It is not yet known whether special belts or headbands having large numbers of small electrodes designed especially for EIT applications might considerably improve this situation. But, regardless of such possible advances in technology, it is not anticipated that EIT will ever "outresolve" methods like x-ray CT.

At the present time, EIT is the only method known that images electrical conductivity, although MRI and electromagnetic methods also have some potential to measure conductivity. So, for applications requiring knowledge of the distribution of this parameter through a body, EIT will continue to be an important method to consider for medical imaging, regardless of its resolving power.

On the other hand, EIT has some very attractive features. The technology for doing electrical impedance imaging is safe and inexpensive, and therefore could be made available at multiple locations (for example, at bedside) in hospitals. At the low current levels needed for this imaging technique, the method is not known to cause any long-term harm to the patient, and therefore could be used to do continuous (or frequent, but intermittent) monitoring of bedridden patients. Technology for acquiring data, and algorithms for inverting that data to produce images of conductivity/resistivity, have been developed to the point that real-time imaging could become routine today using a graphics workstation as the computing platform.

9.3 Present Status of EIT and Limitations

The impedance imaging problem is nonlinear and extremely ill posed, which means that large changes in interior properties can result in only small changes in the measurements. This implies that making a high-resolution image would require extremely accurate measurements, which in turn makes the problem of designing appropriate electronics very challenging.

At present there are two main approaches to the problem. The first, called the applied potential tomography (APT) system, was developed by Barber and Brown in Sheffield, England. Surrounding the body by a ring of 16 electrodes, they used a single current generator to pass current between a pair of adjacent electrodes and measure the voltage on all the other electrodes; they then connected the current generator to the next pair of adjacent electrodes, and so on, until all adjacent pairs had served as "driver pairs." This approach has the advantage of simplicity of design, but its resolution is intrinsically limited; it is also sensitive to small errors in electrode placement. Because of this sensitivity, the APT system cannot make images of the electrical parameters themselves, but can only display changes. This system has been used in studies of various physiological processes, including gastric emptying, blood flow in the thorax, head, and arm, and pulmonary ventilation.

The second approach to impedance imaging is the adaptive current tomograph (ACT), developed by a team at Rensselaer Polytechnic Institute. These systems use 32 or 64 electrodes, each with its own programmable current generator. Although this design is more complicated, it overcomes many of the limitations of the APT design: ACT systems are optimal in the sense that they extract the maximum possible information, and they are less sensitive to electrode placement errors. ACT systems have produced images of the electrical conductivity and permittivity in the human thorax, and have been used in breast studies.

The amount of research in EIT is increasing rapidly. Most of this research is taking place in Europe, where researchers have worked on topics ranging from system design and reconstruction algorithms to clinical applications. Most of the U.S. research, other than that of the Rensselaer group, has been concerned with mathematical aspects of the reconstruction problem; see section 14.1.5.

9.4 Research Opportunities

- Development of a realistic model that describes the multiple path problem, and development of mathematical methods of tomography that respect the physics of multipath incoherent diffusion.

- Clinical research performed to determine the role of impedance imaging for applications such as determination of cardiac output, monitoring for pulmonary edema, and screening for breast cancer.

9.5 Suggested Reading

1. Barber, D.C., Electrical impedance tomography, in *The Biomedical Engineering Handbook,* J.D. Bronzino, ed., CRC Press, Boca Raton, Fla., 1995, 1151–1164.

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