March 1983 Vol. 71 No. 3

PROCEEDINGS OF THE IEEE

Scanning the Issue

THE SPECIAL ISSUE ON COMPUTERIZED TOMOGRAPHY

THE PROBLEM of image reconstruction from projections has arisen independently in a large number of scientific fields. An important version of the problem in medicine is that of obtaining the internal structure of the human body from multiple projections obtained using X-rays, γ-rays, ultrasound, etc. This process is referred to as *computerized tomography* (CT); it has revolutionized diagnostic radiology over the past decade. The 1979 Nobel Prize in medicine has been awarded for work on computerized tomography. The 1982 Nobel Prize in chemistry has also been awarded for work on image reconstruction: this time for the reconstruction of viruses and macromolecules from electron micrographs.

There is a large literature on image reconstruction from projections; there are already several books devoted to its mathematical, computational, and other technical aspects [1]-[4]. The purpose of this Special Issue is to introduce the electrical engineering community (in its broadest sense) to the field of medical computerized tomography by a series of in-depth and up-to-date tutorial articles.

The issue is divided into two roughly equal parts: i) medical applications and ii) theoretical foundations. Since the medical aim and efficacy of CT can be appreciated even without understanding the science on which it is based, the issue has been organized with the somewhat unusual direction of going from application to theory.

The article by Axel, Arger, and Zimmerman (three clinical radiologists) discusses the medical use of the work-horse of the field: a standard X-ray CT scanner. It provides a simple description of the nature of CT and illustrates its application to both the head and the body.

A special area of application is to the heart: cardiac computerized tomography is reviewed by Boyd and Lipton. They discuss both the cardiac diagnostic problems suitable for CT and the way current and developmental scanners are applied to these problems.

One such developmental scanner is the dynamic spatial reconstructor. Robb *et al.* discuss how this machine was designed to allow stop-action high-repetition-rate volume imaging of the heart, lung, and circulation.

These first three articles deal with reconstruction based on X-rays. The article by Knoll introduces single-photon emission CT (SPECT). Here the source of radiation is a radioisotope that is distributed within the body and the objective is to provide a spatial map of this distribution, which, in turn, can often indicate various aspects of physiological function.

An alternative energy that can be used for CT is ultrasound; the theoretical and practical problems associated with this are discussed by Greenleaf. The great variety of ways ultrasound interacts with tissue makes ultrasound a potentially useful source of varied information, but it also causes great difficulties in unraveling this information.

Nuclear magnetic resonance (NMR) imaging is the latest addition to the tools of the diagnostic radiologist. Hinshaw and Lent carefully introduce this modality to the uninitiated; they show how the consequences of the so-called Bloch equation can be exploited by an appropriate physical system to produce clinically useful images.

The part on medical application is concluded by the article of Bloch and Udupa, who discuss how CT, in conjunction with three-dimensional display techniques, can be applied to planning a course of radiation therapy for a cancer patient and for planning a surgical procedure.

The article by Bates, Garden, and Peters acts as a bridge between the medical applications and the theoretical foundations. It provides a descriptive account of computerized tomography defined in its broadest sense, discusses problem areas of existing CT systems, and sketches promising future approaches.

Macovski concentrates on the physical problems that arise in CT. These include nonlinearities (where the mathematical model assumes linearity), insufficient data, and noise in the measurements.

The mathematics of CT predates CT by a good 50 years: the problem of recovering a function from its line integrals was solved by Radon [5] in 1917. Nevertheless, there remain interesting mathematical problems, such as "To what extent the object is determined by the data?" and "How stable the reconstructions are with respect to data errors?". Such problems are discussed by Louis and Natterer.

0018-9219/83/0300-0291$01.00 © 1983 IEEE

Reconstruction algorithms are the computer methods by which the measurements are turned into reconstructions. Transform methods are those which are essentially numerical implementations of a closed-form inversion formula, such as the one due to Radon [5]. Such methods are the ones commonly used in most applications of CT, they are discussed in great detail by Lewitt.

An alternative approach to reconstruction is the use of a series expansion, in which the image domain is digitized prior to any mathematical analysis. Censor gives a tutorial of such methods, alternatively known as algebraic methods, iterative algorithms, and optimization techniques.

Finally, the article by Udupa gives the theoretical foundation to displaying the three-dimensional information which exists in the three-dimensional scenes produced by CT. The impatient reader may wish to glance at his final figures: the three-dimensional displays of a patient's skull (based on X-ray CT) and of a beating heart (based on NMR) should motivate him in reading through the rest of the issue.

What is missing from the issue? Given its aim (full coverage of the theory and applications of medical CT for electrical engineers), two additional topics could have been given articles of their own. Positron emission tomography (PET), in which pairs of γ-rays are produced and detected, is related but by no means identical to SPECT. The reader is referred to the relevant articles in [1] and [3] for technical information, and to [6] for a more popular description. There is also no article in this issue devoted to the engineering of CT scanners. Some relevant articles appeared in [3].

Finally, there are many nonmedical applications of image reconstruction. These were on purpose excluded, see [1], [2] for examples. A further example appeared in the last issue of PROCEEDINGS OF THE IEEE which contained an article by Mensa, Halevi, and Wade on coherent Doppler tomography for microwave imaging.

REFERENCES

[1] G. T. Herman, Ed., *Image Reconstruction from Projections: Implementation and Applications.* Berlin, Germany: Springer, 1979.

[2] G. T. Herman, *Image Reconstruction from Projections: The Fundamentals of Computerized Tomography.* New York, NY: Academic Press, 1980.

[3] T. H. Newton and G. Potts, Eds., *Technical Aspects of Computed Tomography*, vol. V of *Radiology of the Skull and Brain.* St. Louis, MO: C. V. Mosby, 1981.

[4] G. T. Herman and F. Natterer, Eds., *Mathematical Aspects of Computerized Tomography.* Berlin, Germany: Springer, 1981.

[5] J. Radon, "Uber die Bestimmung von Funktionen durch ihre Integralwerte längs gewisser Mannigfaltigkeiten," *Saechsische Berichte Akademie der Wissenschaften*, vol. 69, pp. 262–277, 1917.

[6] M. M. Ter-Pogossian, M. E. Raichle, and B. E. Sobel, "Positron emission tomography," *Sci. Amer.*, vol. 243, no. 4, pp. 171–181, 1980.

GABOR T. HERMAN
Guest Editor

Gabor T. Herman (M'79–SM'82) was born in Budapest, Hungary, on March 30, 1941. He received the M.Sc. degree in mathematics from the University of London, England, in 1964, the M.S. degree in engineering science from the University of California in 1966, and the Ph.D. degree in mathematics from the University of London, England, in 1968.

During 1966–1967, he was a Lecturer in Computer Science at Brighton College of Technology, England. From 1967–1969, he was an Instructor with IBM (UK) Ltd. From 1969 to 1981, he was with the Department of Computer Science, State University of New York at Buffalo, Amherst, NY. During 1975–1976, he was a Visiting Professor in the Biophysical Sciences Unit at the Mayo Clinic in Rochester, MN. In 1976, he became the Director of the Medical Image Processing Group in the Department of Computer Science at SUNY at Buffalo. Currently, he is a Professor and Chief of the Medical Imaging Section in the Department of Radiology at the Hospital of the University of Pennsylvania, Philadelphia. He has published over 135 scientific papers mostly on topics in biomedically motivated computer science. He has written and edited several books, including Computer Aided Tomography and Ultrasonics in Medicine *(North-Holland, 1979),* Image Reconstruction from Projections: Implementation and Applications *(Springer, 1979),* Image Reconstruction from Projections: The Fundamentals of Computerized Tomography *(Academic Press, 1980), and* Mathematical Aspects of Computerized Tomography *(Springer, 1981). He is on the Editorial Board of* Magnetic Resonance Imaging *and is an Associate Editor of* Computerized Radiology, Computer Graphics and Image Processing, *and* IEEE TRANSACTIONS ON MEDICAL IMAGING.

Dr. Herman is a member of the American Association of Physicists in Medicine, the Association for Computing Machinery, the British Computer Society, the Mathematical Programming Society, the Radiological Society of North America, the American Society of Neuro-Imaging, the Society for Industrial and Applied Mathematics, and the Society for Photo-Optical Instrumentation Engineers.