

ADVANCES IN NONINVASIVE CARDIOLOGY

Ultrasound, computed tomography,
radioisotopes, digital angiography

edited by

Jurgen Meyer, Peter Schweizer,
and Raimund Erbel

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JÜRGEN MEYER, MD
PETER SCHWEIZER, MD
RAIMUND ERBEL, MD

*Department of Internal Medicine I
Rheinisch-Westfälische Technische Hochschule
Aachen
Federal Republic of Germany*



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1B

PREFACE

Many noninvasive examination methods of the heart have not held out against the invasive methods, which modern cardiac therapy, surgically or with catheterization, requires. They have disappeared completely or are only used by isolated groups of researchers. However, there is an obvious tendency to apply the invasive procedures as the last diagnostic possibility.

In the attempt to select clinically relevant methods, the expert authors of this book demonstrate that echocardiography, expanded with contrast and Doppler, has been developed into one of the most important noninvasive methods. The results with tissue characterization show that the possibilities of this method have not yet been fully explored.

Nuclear procedures are widely used, although they should only be applied in direct connection with clinical cardiology.

The new lead methods of the ecg, such as ecg-mapping, show that standard electrocardiography of electrical functions is not yet fully exploited.

The rapidly developing method of computer tomography is also being applied to cardiology. Since nuclear magnetic resonance requires extensive equipment construction, its future is as yet unsure.

Of course, a book like this does not intend to treat the subject of noninvasive cardiology in extensive detail. Established methods like standard electrocardiography, phonocardiography and sphygmography are not discussed. The aim of this book is rather to demonstrate the trend of present developments in the field.

LIST OF CONTRIBUTORS

- Ameling, W., Rogowski-Institut für Elektronik, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27/29, D-5100 Aachen, FRG.
- Bachmann, K., Medizinische Poliklinik, Universität Erlangen-Nürnberg, Östliche Stadtmauerstrasse 29, D-8520 Erlangen, FRG.
- Baumer, A., Radiologische Universitätsklinik, Klinikum Grosshadern, Marchionistrasse 15, D-8000 München 70, FRG.
- Bethge, H.D., Medizinische Poliklinik, Universität Erlangen-Nürnberg, Östliche Stadtmauerstrasse 29, D-8520 Erlangen, FRG.
- Bleifeld, W., Universitätskrankenhaus Eppendorf, Medizinische Klinik, Kardiologische Abteilung, Martinistrasse 52, D-2000 Hamburg 20, FRG.
- Bom, A.H.A., Interuniversity Cardiology Institute and Thorax Centre, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.
- Bookstein, F.L., Division of Radiologic Physics, Department of Radiology, University of Michigan, Ann Arbor, MI 48109, USA.
- Brennecke, R., Abteilung für Kinderkardiologie und Biomedizinische Technik, Klinikum der Christian-Albrechts-Universität, Schwanenweg 20, D-2300 Kiel 1, FRG.
- Brower, R.B., Interuniversity Cardiology Institute and Thorax Centre, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.
- Brundage, B., Department of Radiology and Medicine and Cardiovascular Research Institute, University of California, Medical Center, San Francisco, CA 94143, USA.
- Brutsaert, P., Department of Physiology, University of Antwerp (RUCA), Groenenborgerlaan 171, B-2020 Antwerp, Belgium.
- Buda, A.J., Division of Cardiology, University Hospital, 1405 East Ann Street, Ann Arbor, MI 48109, USA.
- Bürsch, J.H., Abteilung für Kinderkardiologie und Biomedizinische Technik, Klinikum der Christian-Albrechts-Universität, Schwanenweg 20, D-2300 Kiel 1, FRG.
- Cannon, S., Cardiology, Veterans Hospital University of Texas Health Science Center, San Antonio, TX 78284, USA.
- Chivers, R.C., Physics Department, University of Surrey, Guildford, Surrey GU2 5XH, United Kingdom.
- Claes, V.A., Department of Physiology, University of Antwerp (RUCA), Groenenborgerlaan 171, B-2020 Antwerp, Belgium.
- Collins, S.M., Department of Electrical and Computer Engineering, University of Iowa, Iowa City, IO 52242, USA.
- Daniel, W.G., Medizinische Hochschule Hannover, Abteilung für Kardiologie, Konstanty-Gutschow-Strasse 8, D-3000 Hannover 61, FRG.
- Delp, E.J., Department of Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI 48109, USA.
- Distante, A., Istituto di Fisiologia Clinica, CNR e Università di Pisa, Via Savi 8, I-56100 Pisa, Italy.

- Döhring, W., Medizinische Hochschule Hannover, Abteilung für Kardiologie, Konstanty-Gutschow-Strasse 8, D-3000 Hannover 61, FRG.
- Effert, S., Abteilung Innere Medizin I, Medizinische Fakultät, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Erbel, R., Abteilung Innere Medizin I, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, BRD. Present address: II. Medizinische Klinik und Poliklinik, Johannes Gutenberg Universität, Langenbeckstrasse 1, D-6500 Mainz, FRG.
- Essen von, R., Abteilung Innere Medizin I, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Fischbach, T., Medizinische Einrichtungen der Universität Düsseldorf, I. Medizinische Klinik B, Moorenstrasse 5, D-4000 Düsseldorf 1, FRG.
- Goldstein, J., Departments of Radiology and Medicine and the Cardiovascular Research Institute, University of California, Medical Center, San Francisco, CA 94143, USA.
- Hanrath, P., Universitätskrankenhaus Eppendorf, Medizinische Klinik, Kardiologische Abteilung, Martinistrasse 52, D-2000 Hamburg 20, FRG.
- Hauke, R., Toshiba Medical Systems, Grafenberger Allee 115-117, D-4000 Düsseldorf 1, FRG.
- Heintzen, P.H., Abteilung Kinderkardiologie und Biomedizinische Technik, Klinikum der Christian-Albrechts-Universität, Schwanenweg 20, D-2300 Kiel 1, FRG.
- Herfkens, R., Department of Radiology and Medicine and the Cardiovascular Research Institute, University of California, Medical Center, San Francisco, CA 94143, USA.
- Hinsen, R., Helmholtz Institute for Biomedical Engineering, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Huang, S.C., University of California, Laboratory of Nuclear Medicine, UCLA School of Medicine, Los Angeles, CA 90024, USA.
- Jehle, J., Medizinische Einrichtungen der Universität Düsseldorf, I. Medizinische Klinik B, Moorenstrasse 5, D-4000 Düsseldorf 1, FRG.
- Jenkins, J.M., Department of Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI 48109, USA.
- Jensch, P., Rogowski-Institut für Elektronik, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, FRG.
- Katen ten, H.J., Interuniversity Cardiology Institute and Thorax Centre, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.
- Kirsch, C.M., Radiologische Universitätsklinik, Klinikum Grosshadern, Marchionistrasse 15, D-8000 München 70, FRG.
- Köster, O., Department of Radiology, University of Bonn, Sigmund-Freud-Strasse, D-5300 Bonn-Venusberg, FRG.
- Kramer, P., Departments of Radiology and Medicine and the Cardiovascular Institute, University of California, Medical Center, San Francisco, CA 94143, USA.
- Krebs, W., Abteilung Innere Medizin I, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Kubalski, W., Rogowski-Institut für Elektronik, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Lackner, K., Department of Radiology, University of Bonn, Sigmund-Freud-Strasse, D-5300 Bonn-Venusberg, FRG.
- Langenstein, B.A., Universitätskrankenhaus Eppendorf, Medizinische Klinik, Kardiologische Abteilung, Martinistrasse 52, D-2000 Hamburg 20, FRG.
- Lauber, A., Medizinische Einrichtungen der Universität Düsseldorf, I. Medizinische Klinik B, Moorenstrasse 5, D-4000 Düsseldorf 1, FRG.
- Lichtlen, P.R., Medizinische Hochschule Hannover, Abteilung für Kardiologie, Konstanty-Gutschow-Strasse 8, D-3000 Hannover 61, FRG.
- Lipton, M.J., Departments of Radiology and Medicine and Cardiovascular Research Institute, Uni-

- versity of California, Medical Center, San Francisco, CA 94143, USA.
- Marhoff, P., Abteilung Medizin-Technik, Siemens, Erlangen, FRG.
- Melton, H.E., Department of Electrical and Computer Engineering, University of Iowa, Iowa City, IA 52242, USA.
- Merx, W., Abteilung Innere Medizin I, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Meyer, C.R., Division of Radiologic Physics, Department of Radiology, University of Michigan, Ann Arbor, MI 48109, USA.
- Meyer, J., Abteilung Innere Medizin I, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, BRD. Present address: II. Medizinische Klinik und Poliklinik, Johannes-Gutenberg Universität, Langenbeckstrasse 1, D-6500 Mainz, FRG.
- Meyer-Ebrecht, D., Philips GmbH, Forschungslaboratorium Hamburg, Vogt-Köllnstrasse 30, D-2000 Hamburg, FRG.
- Ocken van, E., Department of Physiology, University of Antwerp (RUCA) Groenenborgerlaan 171, B-2020 Antwerp, Belgium.
- Ogris, E., Kardiologische Universitätsklinik, Allgemeines Krankenhaus der Stadt Wien, Garnison-gasse 14, A-1097 Wien, Austria.
- Pachinger, O., Kardiologische Universitätsklinik, Allgemeines Krankenhaus der Stadt Wien, Garnison-gasse 14, A-1097 Wien, Austria.
- Phelps, M.E., University of California, Laboratory of Nuclear Medicine, UCLA School of Medicine, Los Angeles, CA 90042, USA.
- Pitt, B., Division of Cardiology, University Hospital, 1405, East Ann Street, Ann Arbor, MI 48109, USA.
- Pölit, B., Medizinische Einrichtungen der Universität Düsseldorf, I. Medizinische Klinik B, Moorenstrasse 5, D-4000 Düsseldorf, FRG.
- Probst, P., Kardiologische Universitätsklinik, Allgemeines Krankenhaus der Stadt Wien, Garnison-gasse 14, A-1097 Wien, Austria.
- Rau, G., Helmholtz-Institut, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Richards, K.L., Department of Cardiology, Veterans Hospital and University of Texas Health Science Center, San Antonio, TX 78284, USA.
- Rienmüller, R., Radiologische Universitätsklinik, Klinikum Grosshadern, Marchioninistrasse 15, D-8000 München 70, FRG.
- Roelandt, J., Thorax Centre, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.
- Schelbert, H.R., University of California, Laboratory of Nuclear Medicine, UCLA School of Medicine, Los Angeles, CA 90024, USA.
- Schenkels, P., Department of Physiology, University of Antwerp (RUCA), Groenenborgerlaan 171, B-2000 Antwerp, Belgium.
- Schicha, H., Division of Nuclear Medicine, University of Göttingen, Robert-Koch-Strasse 40, D-3400 Göttingen, FRG.
- Schlüter, M., Universitätskrankenhaus Eppendorf, Medizinische Klinik, Kardiologische Abteilung, Martinistrasse 52, D-2000 Hamburg, FRG.
- Schmiel, F.K., Medizinische Einrichtungen der Universität Düsseldorf, I. Medizinische Klinik B, Moorenstrasse 5, D-4000 Düsseldorf I, FRG.
- Schwaiger, M., University of California, Laboratory of Nuclear Medicine, UCLA School of Medicine, Los Angeles, CA 90024, USA.
- Schweizer, P., Abteilung Innere Medizin I, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, BRD. Present address: Evangelisches Krankenhaus, Ferrenbergstrasse 24, 5060 Bergisch-Gladbach 2, FRG.
- Serruys, P., Interuniversity Cardiology Institute and Thorax Centre, Erasmus University Rotterdam,

- P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.
- Shah, A., University of California, Laboratory of Nuclear Medicine, UCLA School of Medicine, Los Angeles, CA 90024, USA.
- Silny, H., Helmholtz Institute for Biomedical Engineering, Rheinisch-Westfälische Technische Hochschule, Goethestrasse 27-29, D-5100 Aachen, FRG.
- Skorton, D.J., Department of Internal Medicine, University of Iowa and Iowa City VA Medical Center, Iowa City, IA 52242, USA.
- Smith, D.N., Department of Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI 48109, USA.
- Sochor, H., Kardiologische Universitätsklinik, Allgemeines Krankenhaus der Stadt Wien, Garnisonsgasse 14, A-1097 Wien, Austria.
- Spiller, P., Medizinische Einrichtungen der Universität Düsseldorf, I. Medizinische Klinik B, Moorenstrasse 5, D-4000 Düsseldorf 1, FRG.
- Stender, H.St., Medizinische Hochschule Hannover, Abteilung für Kardiologie, Konstanty-Gutschow-Strasse 8, D-3000 Hannover 61, FRG.
- Strauer, B.E., Medizinische Klinik I, Klinikum Grosshadern, Marchionistrasse 15, D-8000 München 70, FRG.
- Thier, W., Universitätskrankenhaus Eppendorf, Medizinische Klinik, Kardiologische Abteilung, Martinistrasse 52, D-2000 Hamburg, FRG.
- Thuru, P., Department of Radiology, University of Bonn, Sigmund-Freud-Strasse, D-5300 Bonn-Venusberg, FRG.

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I. ADVANCES IN METHODOLOGY

1. COMPUTER STRUCTURES FOR DIGITAL IMAGING

WALTER AMELING

1. INTRODUCTION

In the near future most areas of the medical field will be confronted with data-gathering and computer-systems. Therefore it is worthwhile looking at the main problems and criteria which are involved with such systems. Methods and models have to be discussed which will very soon lead to technical restrictions and limitations for the application, especially in the area of *online-computing*. Nowadays the speed of single- or multiprocessor-systems enables mathematical and statistical describing functions to be used, which were not thought about some years ago. The evolution in technology allows us today to realize computer-systems which are highly flexible, expandable, very efficient and easy to adapt to different problems. First we have to recognize that the only way to increase the speed and power of a computer-system in a given technology is by *parallel processing*; that means we are led to complex computer structures, e.g. multiprocessor-systems. In the medical field, especially for digital image processing, we need extremely powerful systems for online and real-time computation.

In this paper the different aspects of *static and dynamic image analysis* and the related computer systems are discussed. We will determine the limitations and different parameters which rule the system-design and the specifications. Images are usually analyzed for:

- image enhancement
 - (noise filtering, contrast enhancement, color enhancement, restoration of defocused and motion-blurred images)
- geometric manipulations
(image rotation, zooming, scrolling, topographic operations, transformation)
- image classification
(pattern recognition, feature extraction)
- image sequence processing
(flow analysis).

Tasks for the analysis of image sequences, so called dynamic image processing, are transient recording, real-time-filtering and fast data processing. The necessary high

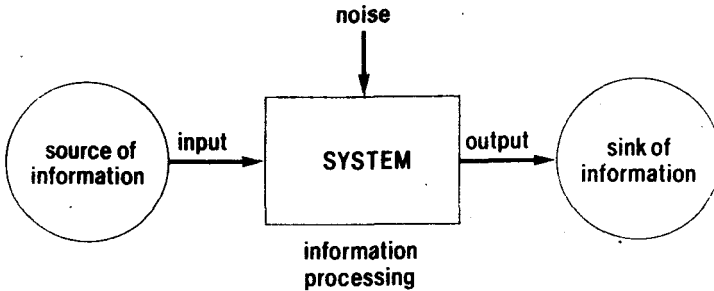


Figure 1. Information processing system.

performance can be achieved by independent data and/or instruction paths. These features lead to pipeline and/or parallel processing.

The optical nature of images originally requires optical manipulation. Since images have to be converted, the optical information has to be converted (film, video-tape). This simplifies image processing very much, because optical manipulations are much more difficult than analog or digital ones. The high processing speed and high accuracy of modern digital computers have restrained analog processing, so that nearly all image processing is done digitally today. As an example of a *digital image processing* system, the ISPS system developed at the Rogowski Institute, Aachen Technical University, is presented. The high performance in this case is achieved by parallel data handling and processing due to multi-port devices, use of a multiprocessor subsystem and independent data paths.

2. CHARACTERISTIC VARIABLES OF ONLINE-PROCESSING

The common operational principle of different information processing systems is shown in Figure 1. An arbitrary source inputs the information to the system which then processes and outputs it to the information sink. The processing system computes the output information according to a given function. In the area of measuring devices the main function is to provide maximum coincidence of input and output information (minimum distortions). In the area of data processing (e.g. automatic measuring and value processing) more complex functions are used to eliminate distortions caused by external noise and to compute characteristic properties of the input information. This provides support in diagnosis for medical applications, because carefully registered and well documented data are required.

Information processing in most cases requires *conversions* (e.g. analog-digital conversion) without loss of information (Figure 2). Unfortunately any conversion adds some noise, which may cause errors in processing later on. In order to provide an adequate conversion we have to consider all parameters of an information-

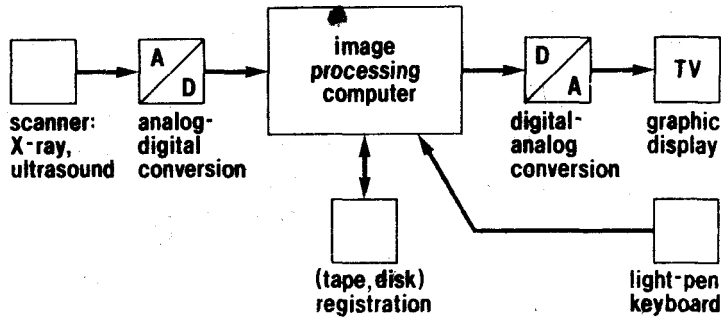


Figure 2. Image processing system.

carrying signal. Most signals carry information as intensity levels dependent on time. The simplest signal of this kind is a *sinusoidal wave* $x(t)$

$$x(t) = \hat{x} \cdot \sin(\omega t + \varphi)$$

where $\hat{x}$ is the peak intensity, φ is the phase shift and ω is the radian frequency.

However, most signals are not sinusoidal. Any periodic signal $f(t)$ can be approximated by a sum $g(t)$ of sinusoidal signals (harmonics) with different intensities and frequencies:

$$g(t) = \frac{a_0}{2} + \sum_{m=1}^n a_m \cdot \cos(m\omega t) + \sum_{m=1}^n b_m \cdot \sin(m\omega t)$$

with:

$$\frac{a_0}{2} = \frac{1}{T} \cdot \int_{t_0}^{t_0+T} f(t) dt$$

$$a_m = \frac{2}{T} \cdot \int_{t_0}^{t_0+T} f(t) \cos(m\omega t) dt \quad m \neq 0$$

$$b_m = \frac{2}{T} \cdot \int_{t_0}^{t_0+T} f(t) \sin(m\omega t) dt.$$

The accuracy of the approximation is the better the larger the number n of harmonics. Non-periodic signals can be approximated in a similar way: the discrete frequency spectrum is replaced with a continuous one. In either case, a characteristic property of the signal is the frequency of the highest harmonic.

In order to digitize an analog signal, it has to be divided into discrete-time and discrete-intensity values. *Shannon's theorem* requests that the sampling rate f_s of an A/D-converter at minimum must be twice the frequency f_g of the highest harmonic:

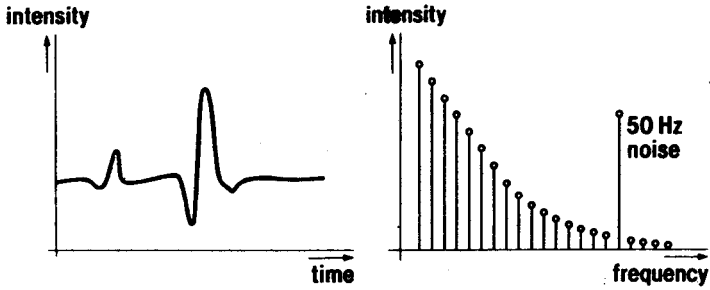


Figure 3. ECG-signal and its Fourier transform.

$$f_a \geq 2 \cdot f_g.$$

An ECG-A/D-converter therefore must provide a minimum sampling rate of 100 Hz since the highest harmonic is about 50 Hz. Sampling rates of 200 Hz to 250 Hz are common today (Figure 3).

The sampling rate f_a gives us the maximum time U_T for conversion:

$$U_T \leq \frac{1}{f_a}.$$

τ is the step size for the discrete-time axis. For ECG-applications U_T is 4 to 5 ms.

3. REQUIREMENTS ON THE COMPUTER SYSTEM

In order to determine the *data-input-rates* to the computer, we look at different applications:

- online ECG-classification (for comparison reasons only)
- offline 2D and 3D image processing
- online 2D and 3D image processing.

These applications differ in the number of variables involved and the restrictions of processing time:

- *two variables:*
 - (a) intensity over time or
 - (b) intensity over 1D-position.

ECG-classification is a typical example of medical applications. The sampling rate of the A/D-conversion is 200 Hz, the intensity resolution is 256 steps. This results in 8 bit every 5 ms, i.e. the data-transfer rate is 1600 bit/s.