ADVANCES IN NONINVASIVE CARDIOLOGY

Ultrasound, computed tomography, radioisotopes, digital angiography

edited by
Jurgen Meyer, Peter Schweizer,
and Raimund Erbel

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1983 **MARTINUS NIJHOFF PUBLISHERS**
a member of the KLUWER ACADEMIC PUBLISHERS GROUP
BOSTON / THE HAGUE / DORDRECHT / LANCASTER

Distributors

for the United States and Canada: Kluwer Boston, Inc., 190 Old Derby Street, Hingham, MA 02043, USA
for all other countries: Kluwer Academic Publishers Group, Distribution Center, P.O.Box 322, 3300 AH Dordrecht, The Netherlands

Library of Congress Cataloging in Publication Data

Main entry under title:

Advances in noninvasive cardiology.

(Developments in cardiovascular medicine)
Includes index.
1. Diagnosis, Noninvasive--Addresses, essays, lectures. 2. Heart--Diseases--Diagnosis--Addresses, essays, lectures. I. Meyer, Jürgen, MD. II. Schweizer, Peter, MD. III. Erbel, Raimund. IV. Series. [DNLM: 1. Heart diseases--Diagnosis. 2. Heart function tests-Methods. W1 DE997VME]
RC683.5.N65A38 1983 616.1'20754 83-6267
ISBN 0-89838-576-8

ISBN 0-89838-576-8

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PRINTED IN THE NETHERLANDS

ADVANCES IN NONINVASIVE CARDIOLOGY

DEVELOPMENTS IN CARDIOVASCULAR MEDICINE

Lancée CT, ed: Echocardiology. 1979. ISBN 90-247-2209-8.
Baan J, Arntzenius AC, Yellin EL, eds: Cardiac dynamics. 1980. ISBN 90-247-2212-8.
Thalen HJT, Meeře CC, eds: Fundamentals of cardiac pacing. 1970. ISBN 90-247-2245-4.
Kulbertus HE, Wellens HJJ, eds: Sudden death. 1980. ISBN 90-247-2290-X.
Dreifus LS, Brest AN, eds: Clinical applications of cardiovascular drugs. 1980. ISBN 90-247-2295-0.
Spencer MP, Reid JM, eds: Cerebrovascular evaluation with Doppler ultrasound. 1981. ISBN 90-247-90-247-2348-1.
Zipes DP, Bailey JC, Elharrar V, eds: The slow inward current and cardiac arrhythmias. 1980. ISBN 90-247-2380-9.
Kesteloot H, Joossens JV, eds: Epidemiology of arteral blood pressure. 1980. ISBN 90-247-2386-8.
Wackers FJT, ed: Thallium – 201 and technetium-99m-pyrophosphate myocardial imaging in the coronary care unit. 198. ISBN 90-247-2396-5.
Maseri A, Marchesi C, Chierchia S, Trivella MG, eds: Coronary care units. 1981. ISBN 90-247-2456-2.
Morganroth J, Moore EN, Dreifus LS, Michelson EL, eds: The evaluation of new antiarrhythmic drugs. 1981. ISBN 90-247-2474-0.
Alboni P: Intraventricular conduction disturbances. 1981. ISBN 90-247-2483-X.
Rijsterborgh H, ed: Echocardiology. 1981. ISBN 90-247-2491-0.
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Amery A, Fagard R, Lijnen R, Staessen J, eds: Hypertensive cardiovascular disease; pathophysiology and treatment. 1982. ISBN 90-247-2534-8.
Bouman LN, Jongsma HJ, eds: Cardiac rate and rhythm. 1982. ISBN 90-247-2626-3.
Morganroth J, Moore EM, eds: The evaluation of beta blocker and calcium antagonist drugs. 1982. ISBN 90-247-2642-5.
Rosenbaum MB, ed: Frontiers of cardiac electrophysiology. 1982. ISBN 90-247-2663-8.
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Adgey AAJ, ed: Acute phase of ischemic heart disease and myocardial infarction. 1982. ISBN 90-247-2675-1.
Hanrath P, Bleifeld W, Souquet, eds: Cardiovascular diagnosis by ultrasound. Transesophageal, computerized, contrast, Doppler echocardiography. 1982. ISBN 90-247-2692-1.
Roelandt, J., ed: The practice of M-mode and two-dimensional echocardiography. 1983. ISBN 90-247-2745-6.

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.

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CONTENTS

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

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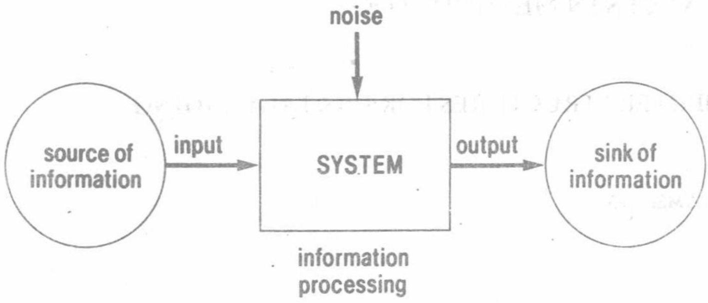

Figure 1. Information processing system.

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 couverted, the optical information has to be couverted (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-

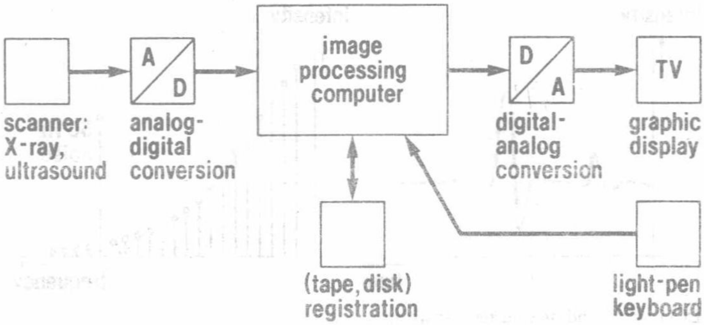

Figure 2. Image processing system.

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:

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

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

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

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_a of an A/D-converter at minimum must be twice the frequency f_g of the highest harmonic:

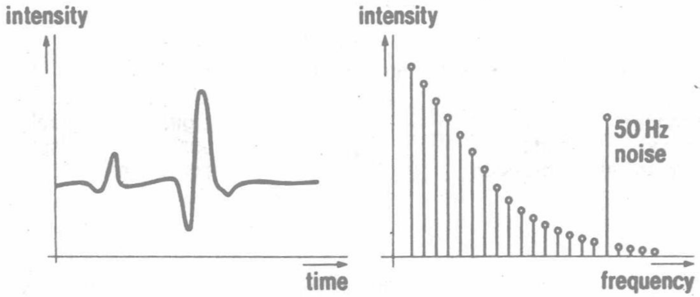

Figure 3. ECG-signal and its Fourier transform.

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

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:

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

U_T 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.