OPTIMIZATION OF COMPUTER ECG PROCESSING

edited by
h. k. wolf & p. w. macfarlane

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Proceedings of the IFIP TC 4 Working Conference on
Optimization of Computer ECG Processing

edited by

Hermann K. WOLF
Dalhousie University
Halifax, Nova Scotia, Canada

and

Peter W. MACFARLANE
University of Glasgow
Glasgow, Scotland

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PREFACE

This book presents the proceedings of an International IFIP TC4 Working Conference on computer-assisted electrocardiography. Previous meetings were held in Hannover in 1971 and Amsterdam in 1976. This meeting focused on the "optimization" of software and hardware used in computer ECG processing; consequently, proceedings from previous meetings will complement this volume. Rapid advances in technology and, in particular, the advent of the microprocessor have had profound implications in the field of computerized ECG interpretation and are reflected in these papers. The principal topics discussed were:

a) Data acquisition, including selection of lead systems; utilization of microprocessor technology; digital recording techniques.

b) data reduction strategies for archival storage and digital transmission.

c) Extraction of wave form features and parameters for clinical classification.

d) classification strategies, including statistical methods, fuzzy set theory and linguistic concepts.

e) systems optimization, including organizational, economical and technical concepts.

Leading experts from Europe, North America and Japan participated in the Conference. Problems of mutual concern were discussed and it was apparent that similar difficulties were encountered in each country, regardless of its particular type of health care system.

Most of the presentations and discussions dealt with problems at the leading edge of the field and this book should, therefore, be of particular interest to those involved in research or development of computer processing of ECGs or related areas of medical computing.

Since the format of a working conference emphasizes discussions in favour of formal presentations, the editors considered it important to include in the proceedings as much of the discussion as possible. It is hoped that the transcription of extemporaneous discussion contributions has, in the final editing process, retained the points of value to the majority of the readers.

The editors are grateful to those discussion participants who reviewed transcripts of their contributions within hours of the sessions to facilitate speedy publication. A number of papers have been extensively revised to improve clarity. The editors have not refereed the papers for scientific content in the usual way and are therefore not always in agreement with the statements made by the authors.

Our one regret is that our own participation in the working discussions was curtailed by our editorial duties.

We are most grateful to our colleagues and co-workers at Dalhousie University who patiently helped in the preparation of the manuscript.

The editors

Peter W. Macfarlane Hermann K. Wolf

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PART I

Working Group 4.3 Report

IFIP TC-4 (IMIA) WORKING GROUP 3
(Guidelines for testing and validating ECG-analysis programs)

BACKGROUND AND INTERIM REPORT

At the IFIP Hannover Conference in 1971, the participants recognized the need for systems evaluation and close cooperation in the field of ECG processing. Thereafter, activities for standardization and collection of validated ECG data were initialized on national bases.

During several national and international conferences, i.e. the 1972 conference in Halifax and the 1973 conference in Turku, it was suggested to seek sponsorship of an international organization for such a cooperative effort. Because of the close connection of IFIP TC-4 to WHO and the resemblance in the basic aims, IFIP TC-4 was chosen and in October 1974, in Toronto, the IFIP general assembly accepted the establishment of the Working Group 4.3.

Several meetings held independently or in connection with other congresses have discussed common problems of computer ECG processing. A monograph entitled "Procedures and Recommendations for Standardized Computer Electrocardiography" has been prepared. It is intended as a reference for system designers and users of computerized ECG analysis.

The purpose of monograph is:

- to identify problem areas in instrumentation, electrocardiographic methods, ECG analysis programs and system evaluation,
- to present up to date standards and recommendations for equipment and methods used in electrocardiography,
- to stimulate the further specification of necessary definitions and standards, especially in measurement and diagnosis,
- to promote the exchange of electrocardiographic data for system evaluation and further development of computerized ECG analysis systems,
- to provide user protection by establishment of minimum performance guidelines and by encouragement of manufacturers, to produce in accordance with these guidelines.

The content of the monograph is organized according to system components: data acquisition, ECG analysis, system evaluation, and ECG-data base.

Each chapter consists of:

a) an introductory comment on the subject together with identification of problem area,
b) a bibliography with key papers which could be used as a basis for more detailed studies,
c) references to established standards, recommendations and proposals,
d) examples of protocols for collection of clinical data for validated electrocardiograms.

The establishment of a data base for testing of ECG signal processing and the development of standards for ECG measurements are now the subject of EEC concerted action projects. Both are directed by Dr. J.L. Willems, Leuven, Belgium (see also these Proceedings).

For the monograph, special position papers on

(1) Selection and Implementation of a Lead System
(2) Methodological Aspects of ECG/VCG Program Evaluation
(3) The Diagnostic-Interpretative Process in the Automated Analysis of Electrocardiograms and Collection of Validated ECGs

have been contributed by (1) H. Ritsema van Eck, Rotterdam; (2) J.L. Willems, Leuven, Ph. Smets, Brussels, J.L. Talmon, Utrecht; (3) J. Michaelis, Mainz, Chr. Zywietz, Hannover, respectively.

The monograph shall be updated as soon as relevant new standards or recommendations are proposed or established. It will be available on request from:

Chr. Zywietz
Medical School of Hannover
P.O. Box 610180
3000 Hannover/Germany

Participation in the work of IFIP TC-4, Working Group 4.3 is on a voluntary basis. The group has been an international composition and currently consists of:

J.H. van Bemmel, R. Bonner, T.E. Cuddy,
H. Ritsema van Eck, L.G. Ekelund, Y. Jokinen,
F. Kornreich, P.W. Macfarlane, J. Michaelis,
J.A. Milliken, B. Olsen, K. Pyorala, P. Smets,
O.B. Wigertz, J.L. Willems, J. Talmon,
H.K. Wolf (Co-Chairman), Chr. Zywietz (Chairman)

Consultants: H.V. Pipberger, P.M. Rautaharju and O.H. Schmitt.

PART II
Data Acquisition

CHAIRMAN'S INTRODUCTION (C. ZYWIETZ)

For the purpose of optimized computer ECG processing three system components which comprise the general area of data acquisition have to be considered:

1. The pick up of the electrical signals through electrodes.

2. The sampling of the electrical heart field by choosing the proper lead system.

3. The technology of ECG recording equiment.

ELECTRODES

The well known model of the skin electrode interface identifies the various sources of problems in the signal pickup. Major difficulties are introduced by the impedance and voltage sources formed between electrodes, gel and skin. These quantities are altered by time, motion artifacts, as well as current flowing between the body and the electrocardiograph. Another problem is caused by the matching of the skin electrode and cable impedance to the input impedance of the amplifier.

The impedance of most electrodes, if normalized for the electrode size, increases with decreasing frequency with the consequence that at low frequencies, amplitude errors often exceed 10%.

Zipp (1) has recently published valuable data for proper adjustment of electrodes, cables and amplifier input specifications on the basis of desired measurement accuracy. The major external problems with electrodes at the present time can be summarized under the following headings.

a) Time consuming application of the electrodes.
b) Unreliable electrode skin interface.
c) Life time of silver-silver chloride electrodes.
d) Variability with time of impedance as well as off-set potential.
e) Difficulty with quality control during recording.
f) Cost.

LEAD SYSTEMS AND INFORMATION EXTRACTION

The information which one wishes to sample from the body surface by means of an electrocardiographic recording system has to be sufficient to allow classification of a patient's state into a large number of possible categories. Taking the classification terminology for myocardial infarction as proposed by the Bethesda Conference Task Force 1 (2) as an example, we find that differentiation with respect to transmural- or nontransmural-infarction, localization of the infarction, age of infarct, and finally the likelihood of the diagnostic statement, leads to 768 possible statements (see accompanying Table 1).

If one adds other category A diagnostic statements for hypertrophy, etc., one obtains 835 diagnostic statements. Logically, an electrocardiographic lead system should be able to provide the information to cover this enormous electrocardiographic semantic space. It is doubtful whether the lead systems which are most commonly used (Einthoven, Goldberger, Wilson, Nehb, Frank) fulfil this requirement.

Table 1

Infarction terminology proposed by Task Force 1 of the 10th Bethesda Conference.

	Localization	State	Likelihood
Non-transmural	Septal	Possibly acute	Cannot exclude
Transmural	Anterior	Probably acute	Possible
	.	.	.
	.	.	.
	.	.	.
	Subendocardial	Probably not acute	
	Segmental	Old	Characteristic
2	12	8	4

Possible combinations - 768!

Although there is no definite method of determining the sampling of the heart field on the body surface necessary to cover the semantic diagnostic space, there exists a rational approach for determining the minimum number of leads in order to recover the electrical field for a given level of accuracy.

With the use of two dimensional Fourier transforms, it is possible to establish the required sampling density in the different areas of the body surface (3).

Figure 1 shows spatial sampling intervals (Nyquist elements) derived from a two-dimensional spatial Fourier transform at QRSmax. The non-rectangular grid together with a reference electrode delineates 33 sampling points on this schematic body surface terminating when cut off was set where the decreasing harmonics fell below 5% of the maximum power in the respective row or column spectrum (left hand side = precordial area). The analysis was undertaken on 7 normal and pathological surface maps with 219 sampling points kindly provided by the group of Professor Taccardi, Milan. From this figure, it is evident that the commonly used lead systems pick up only a minor fraction of the content of the body surface potential distribution. A quantitative figure for this fraction is difficult to define. However, expressed in terms of sample points, it seems to be less than one fourth (8/33) of the necessary leads.

Another objective measure for the potential 'information content' of lead systems is their signal entropy or joint signal entropy (3). Interestingly, Kornreich's 9 lead system (4) shows higher entropy values than other lead systems although the development was based on diagnostic discrimination power.