PROGRESS IN COMPUTER-ASSISTED FUNCTION ANALYSIS

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Proceedings of the IFIP-IMIA Working Conference on
Progress in Biological Function Analysis by Computer Technologies
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PREFACE

This book presents the Proceedings of the International Working Conference on "Progress in Biological Function Analysis by Computer Technologies", which was held in Berlin (GDR) on May 19-23, 1987. It was the first Working Conference of the International Medical Informatics Association (IMIA) in the GDR and the first on this subject by IMIA. The conference was held in Berlin on the 750th anniversary of this historic city. The meeting was attended by more than 200 participants.

The book is composed of 73 papers given by scientists from the whole world, with a strong contribution of the Socialist countries but also with many from the Western Countries. They discussed in an open and friendly atmosphere various methods of information processing for the analysis and assessment of different organ systems, among which the heart and the brain, the respiratory and renal system, as well as overall regulatory processes. There was a strong emphasis on automated EEG analysis and processing of evoked potentials. Perinatal monitoring, ICU and anesthesia monitoring, decision support and expert systems, as well as imaging for function analysis were the themes of the other working sessions.

This book gives a fair reflection of the state of the art in this field and of the achievements made over the last few years. Most of the progress reported at the Conference has been the result of an integrated and interdisciplinary cooperation of physicians, engineers, mathematicians and computer scientists. The application of computer technology and basic methods of signal analysis and pattern recognition was the common denominator for many of the advances made in function analysis. It is a fascinating field where Medical Informatics, Biomedical Engineering and Biomathematics merge and supplement each other. This multidisciplinary approach and the widespread use of advanced computer systems - especially of the ever expanding microcomputer - have been instrumental for the progress and propagation of computer assisted function analysis in various clinical areas in different countries. Applications of computer assisted function analysis are nowadays moving more and more rapidly from the research laboratory to the bedside.

We hope that the reader will be stimulated to use and eventually develop these techniques in order to advance knowledge, but most of all to enhance patient care.

The Editors

Leuven, Jos L. Willems
Rotterdam, Jan H. van Bemmel
Berlin, Joseph Michel

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INTERPRETATION OF BIOSIGNALS for FUNCTION ANALYSIS

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INTRODUCTION

Methods for the processing and interpretation of biological signals are still in continuous evolution, mainly because of the changing processing environment. In this introduction we want to stress the following points: the environment and processing stages of biosignal analysis; the advantages of software modularity; algorithms for the detection of events, segmentation of signal parts, and the classification of waveforms. These points will be illustrated by examples from the interpretation of electro-encephalograms and electrocardiograms, used for function analysis and in intensive care situations.

application areas

Biomedical signal processing and interpretation comprises a wide variety of different applications. We mention just a few of them:

- On-line analysis, taking place in situations where the patient is intensively monitored such as in units for intensive- or coronary care [1], or peri- or postsurgical [2] and perinatal care.
- The assessment of organ function which is done in units for EMG or EEG analysis [3] or for the ECG [4], the phonocardiogram, the spirogram and so on. This same type of signal processing we also encounter in screening areas.
- In more fundamental research signal processing serves the analysis of neuronal or cell depolarizations or the computation of the cardiac depolarization wavefront.
- Last, but not the smallest area in biosignal analysis, is the area of instrumentation and control.

In the following sections we shall discuss examples from these areas, and stress the general methodology behind all applications.

purposes

First we look at the processing environment for function analysis. Generally speaking, data processing for function analysis serves several purposes:

- The support of management and organisation of an entire department, mainly realized by data base management systems (DBMS). A huge quantity of information flows from the patient via transducers or direct observations to the nurse and the physician, both for function analysis and online monitoring. This flow should be reduced, channelled and documented, for which the computer is the ideal vehicle. For medical research but also for legal reasons there is a growing need for data bases, documents, and complete reports in alphanumeric form or as charts and graphs.
- The analysis of alphanumeric, analog and sampled patient data, such as signals, images, biochemical samples and so on, partly done by bedside equipment and processors, partly by other systems, sometimes located at other departments. The sophistication level of this equipment is steadily increasing, since most instruments are being equipped with microcomputers.

The support of medical decision making and trend analysis, e.g. by means of a departmental system and by built-in expert knowledge. Decision making is increasingly based on objective and numerical instead of subjective measurements, for instance derived from signals and images. This also holds for the intervention rules during monitoring. This increased objectivity may lead to the reduction of human errors. The evaluation of the monitoring process and function analysis by colleages or peers will increasingly become a requirement and can be assisted by computerized care. Several processes and even organic functions can also be better followed and understood by the use of (decision) models and simulation.

evolution of systems

The evolution of software and hardware has greatly influenced the way we usu signal interpretation for function analysis. It is not long ago, that home-made instruments were used for biosignal processing and that systems only operated in one's own laboratory. Many researchers struggled with the first A/D converters and signal storage devices. Much of the early equipment was analog or hybrid: almost all of it was special purpose. The fully digital systems with integrated hardware for signal analysis only came in the sixties widely available.
Some signal processing was done on what can be called the expensive mini's of the sixties. Even then, much of the operating systems, device handlers, basic processing routines etc., had to be written by the researchers personally.
In the early seventies it became possible to share systems with other users and to develop general software packages for processing. At that time the first signal processing libraries and a host of routines became available. This time was quickly followed by microprocessors of 8, 16 and now 32 bits of which the M68020 or Intel's 80386 are well-known examples. Signal processing nowadays is easily done on the mighty micro's now available, equipped with large central memory, a hard disk and an operating system with virtual memory. Some systems perform even real-time processing under UNIX; systems are now increasingly integrated in networks.

We also see other components influencing the processing environment of today: graphics and workstations, laser disks and networks with cheap memories for archiving of alphanumeric data, signals and pictures.
But also the software environment has changed quite a bit: there are signal processing packages such as IPL or the IEEE library: image processing packages; interactive pattern recognition systems, such as ISPAHAN [5]; widespread statistical packages, such as

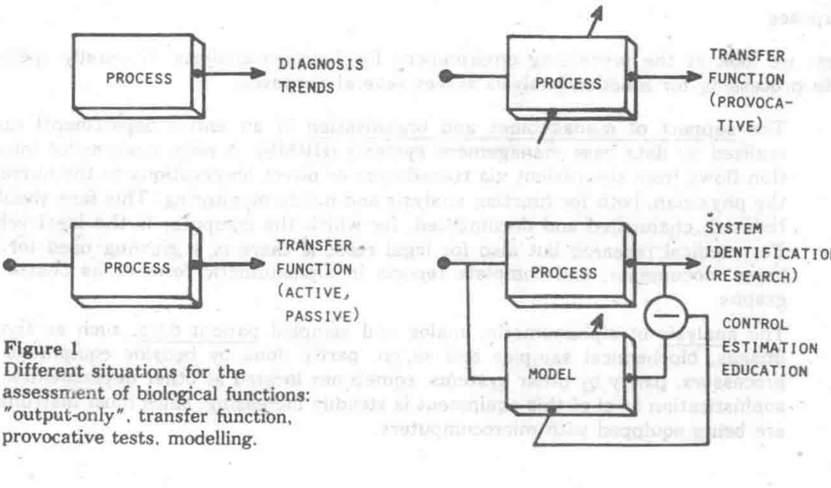

Figure 1
Different situations for the assessment of biological functions: "output-only", transfer function, provocative tests, modelling.

BMDP or SPSS, the latter also available on PC's: the advent of 4th and 5th generation software, such as data base management systems, software tools and expert systems. Such new developments will continue to happen in the future; all of them are influencing the way in which we process biosignals.

PROCESSING SITUATIONS

We could state that, in dealing with biological processes, there are roughly speaking four different situations in which we are confronted with signal analysis, as depicted in Figure 1. In this figure we see that from top to bottom our insight in the process increases. We discuss the four situations consecutively.

- The most common problem in medicine is the situation where we deal with "output-only" (Figure 1a). We know nothing or only some of what is inside the process delivering the signals, which is most often considered as a black box. The approach to be followed in analyzing the output (the signals) is rather empirical. A characteristic example of this situation is EEG interpretation.
- In some cases we know some of the inputs to the process under investigation or we can even offer an input signal (Figure 1b). Ideally, we are then able to compute a transfer function, but - regretfully - most biological processes behave in a non-linear way. Examples of this situation are evoked responses in EEG examinations; stimulation of cells, nerves and muscles; but also pharmacological stimulation may fall in this category.
- A further category are the methods where we want to put the biological process into some forced, or at least known condition (Figure 1c), sometimes combined with a known input stimulus. Many provocative tests fall in this group, such as exercise tests, in which we measure the ECG or the spirogram, EEG analysis, for instance during anesthesia, or atrial pacing.
- In a few cases where we know many more details of the inside of the black box, we might be able to develop a model of the biological process (Figure 1d). Parts of the circulation or the depolarization of the cardiac muscle, as well as compartmental models such as in pharmacokinetics are representative examples. Such models are either used for system identification, in research, or for parameter estimation, process control and, quite often, for educational purposes.

In all four siuations signals are acquired, analyzed and interpreted, sometimes giving rise to on-line feedback to the process itself.

PROCESSING STAGES

Signals stemming from dynamic processes usually have to be preprocessed or transformed before entering the stages of parameter estimation or classification into some signal or pattern category. For all stages of signal interpretation, the proper software has to be available or to be developed. In practice, at each stage several compromises are to be made between some "ideal" theory and its practical realization in order to obtain fast processing and compact data storage. For all stages some optimization process has to be carried out, as we will discuss below. For that purpose a modular set-up of signal processing offers many advantages, as we will show.

The different stages in signal interpretation enable us to split the entire processing in logical subtasks, to be represented by software modules. We shall give an example, by discussing the modular structure of our ECG processing system [6], being very illustrative for biosignal interpretation.

There are several advantages of modular signal processing. As a matter of fact, it is the

MODULAR ECG INTERPRETATION
an example

The ECG is a representative example of the processing of biological signals. In preparing a modular set-up it is first of all - as in all processing problems - important to list all prior knowledge as well as clearly describe the goal of the analysis. In our example we possess much knowledge about the process of depolarization but the repolarization is much less understood; the ECG is a repetitive signal but it contains many stochastic components as well: it has most of the time one dominant waveform but also aspects of point processes; its analysis can be split in modular subtasks: ECG analysis has different applications such as serial analysis, screening, ambulatory monitoring, intensive care, or research. The processing and interpretation itself can be characterized as a mixture of signal analysis and pattern recognition.

Looking at the structure of this modular processing, as seen in Figure 2, we discern first of all the modular package itself, split into an input and an output task, and pattern analysis and classification tasks in between. The pattern analysis can be split into groups of detection, typification and boundary estimation modules. The classification is also subdivided in modules. Such modules are numbered in the order in which they are usually called by the main program. In the following we summarize the signal processing tasks of the different modules.

- The input module takes care of signal acquisition, either sequentially or as 3, 8, 12 or 15 ECG leads simultaneously. It performs the sampling and temporary storage in a predefined file. Several tasks can in principle operate concurrently with each other, which means that the input may still be operational while some of the other modules have already been started. Starting of a module is done on the basis of status flags that are set by preceding modules.
- Detection of events concerns the location of QRS complexes of all shapes by module RFIND, the finding of noise and disturbance and the detection of P waves by PFIND.
- Typification or clustering according to waveshape is done for the QRS complexes in RTYP and for the ST-T complex in STTYP.
- Segmentation or boundary recognition is done for the QRS complex, the T wave and the P wave in ONOFQ, ENDT and ONOFP respectively. The problem is here to locate the onsets and endpoints of certain waves as accurately as possible in order to compute features for diagnostic purposes.
- The last group of modules concerns the diagnostic classification: beat selection and coherent averaging for waveshape analysis BEAT, parameter estimation PARAM, rhythm classification RHYT and the waveshape classification CLASS in diagnostic categories such as LVH, AMI or LBBB.
- The output module takes care of alphanumeric and graphical reports, and the storage of results on some digital storage device such as a disk.

The system as a whole is able to interpret the (simultaneously recorded) 12-lead ECG as well as the VCG. In its early development (beginning of the seventies) it was operational on rather large and expensive minicomputers; nowadays it has been implemented on a PC with industrial standards and with only a minimum of necessary extra hardware (only a set of signal amplifiers and a standard A/D card).