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Guest editorial

Biosignal Processing: the pacemaker for innovations in Biomedical Engineering – state, developments, trends

Driven by the rapid development of microelectronics and microcomputer techniques during the last 30 years, which provide huge computing resources in single devices, the tremendous progress in biosignal processing has become the mainspring for innovations in biomedical engineering. Biosignal processing can be defined as the analysis of signals directly or indirectly generated or modulated by an organism or a structure of organisms within a living entity in order to extract relevant information about the conformation, state and changes in states of such systems. Even small devices such as clinical thermometers contain small inexpensive computing cores, which allow the implementation of powerful procedures for signal processing and are easier to use via active menu navigation. The sources of biosignals exhibit one-dimensional, two-dimensional and multi-dimensional structures and their signals are recorded by appropriate sensors, e.g., the electrocardiogram (ECG) as a one-dimenional time series on the one hand and magnetic resonance imaging (MRI) as a three-dimensional method on the other hand. Considering functional MRI (fMRI), which reflects the time course of the activity of specific brain areas, it becomes obvious that there is no strict distinction between time and image signals and their processing. Nevertheless, this first special issue of *Biomedizinische Technik/Biomedical Engineering* on biosignal processing is mainly dedicated to classical biomedical time series.

Certainly, the ECG represents the most common biosignal of the "human being" system, as it is routinely recorded in physical examinations; using simple evaluation methods, some basic characteristics of heart function can be determined. However, using more sophisticated algorithms, more detailed information can be extracted for diagnosis and for risk stratification, as well as for the control of medical devices (e.g., cardiac pacemaker) – the span of possible new applications appears to be almost unlimited. This is not only true for ECG processing, since biosignal processing constitutes an essential element in many clinical disciplines: in cardiovascular systems, in intensive care, in neurology and neurosurgery, in sleep medicine, in physiotherapy, in rehabilitation and in several other medical fields. In addition, there are application-oriented fields such as sports science, ergonomics, psychology and basic research in biology.

Despite this wide application spectrum, the effective advantage of the potential of biosignal processing in the clinical area does not appear to be fully exploited. For example, routine evaluation of long-term ECG records (Holter ECG) and of electroencephalographic recordings (EEG) in the sleep laboratory is usually computer-aided, but this tedious (and consequently prone to errors) procedure is manually (interactively) performed by a human operator. Moreover, many additional biosignals are recorded during clinical examination and therapy, but they are conventionally evaluated, which underutilizes the possibilities and performance available, even though there might be a great need to obtain more extensive information about the clinical status of the patient, e.g., in intensive care. Obviously, the demand for biosignal analysis tools that are clinically approved and robust still seems to be unfulfilled, which is also true for the clinical interpretation of the parameters extracted. New procedures and algorithms for such biosignal processing applications will be recognized, publicized and introduced into clinical routine only after verification in a large group of patients by providing a significant improvement in diagnosis and/or therapy. To achieve this objective, the competence of the German Association for Biomedical Engineering (DGBMT) in biosignal processing must be more intensively directed towards discussion and cooperation with clinical partners. This will boost the transfer of ideas and solutions developed in basic research to clinical areas, and thus patients will finally benefit. This reasoning highlights the present situation in biosignal processing, namely that, despite the tremendous progress achieved during the last decades, a wide variety of research and development is still required.

It should be noted that even the most perfect processing of biosignals cannot compensate for deficits during recording. Therefore, progress with new sensors and sensor technologies will also drive innovations in biosignal processing. In fact, the increased computational power available for data handling and evaluation allows the redundant observation of physiological processes, which results either in a higher resolution of the process and/or an extended representation of it. However, this additional information will only be helpful if there is adequate progress in the understanding and modeling of physiological processes. A typical example is the electromyographic (EMG) array electrode for surface recording, which allows measurement of EMG signals similar to those recorded using invasive needle electrodes. This new technique can be helpful in the neurological examination of patients with high Makumar medication, for whom invasive techniques cannot be used. In addition, the SQUID technology used to record very weak magnetic fields should also be mentioned, which is used in magneto-encephalography.

The main body of biosignal processing traditionally comprises linear and non-linear methods for signal treatment and information extraction. Continuous enhancement and expansion of these methods to new areas have been indispensable for successful exploitation of the advanced possibilities in microelectronics and computing. The specific problems in applying mathematical and engineering approaches to the analysis and control of physiological systems pose a major challenge to researchers, which was formulated as early as 1966 by H.T. Milhorn [The application of control theory to physiological systems. Philadelphia/London: WB Saunders 1966]:

- The relationship between variables of biological systems mostly behaves in a somewhat non-linear manner.
- Biological systems usually exhibit no intrinsic static equilibrium, but there is continuous control and adjustment.
- The dimensionality of biological systems far exceeds that of technical systems.

During recent years, there has been increased focus on dynamic non-linear methods, chaos-theory-based approaches and model-based signal processing. These innovative but very complex concepts require ample computing resources, but they seem to better match the complexity of the organisms and biological systems investigated. Thus, the non-linear dynamic system approach to heart-rate variability (HRV), for example, provides significant additional diagnostic contributions to the risk stratification of cardiac patients in comparison to linear approaches. Furthermore, model-based analysis of biosignals allows improved parameter extraction in complex phenomena (e.g., source localization in EEG using head models; gait analysis using biomechanical models). These advanced techniques are candidates for new concepts in clinical biosignal processing: they allow dynamic adaptation to the organism observed and facilitate understanding of the underlying physiological process.

These perspectives of new concepts and methods in biosignal processing can provoke novel initiatives in clinical diagnosis, physiomonitoring and treatment control, as well as in the assessment of genetic and pharmacological effects for clinical utilization. In addition, the substitution of sometimes painful, invasive techniques by non-invasive methods that provide equivalent information will trigger new diagnostic and therapeutic concepts. Finally, it should be mentioned that more efficient diagnosis and treatment reduce stress and therapeutic risk for patients.

For all these reasons, DGBMT as part of VDE, together with partner organizations in Austria (ÖGBMT) and Switzerland (SGBT), support the advance in Biosignal Processing in basic research and clinical applications. For example, biosignal processing topics are the focus of attention at the annual DGBMT meeting, and the DGBMT committee on Medical Informatics initiated a special program to support biosignal processing and to enhance synergistic cooperation within German-speaking countries to allow successful participation in the international competition in this field. Within this framework, this special issue of *Biomedizinische Technik/Biomedical Engineering* on biosignal processing was prepared; it is the first part of a collection of more than 50 papers contributed by various universities, research institutions and companies. All of the papers were peer-reviewed and they provide a good survey of actual activities in the field of biosignal processing. The editorial board for this issue consists of:

- Hartmut Dickhaus, University of Applied Sciences Heilbronn, Germany
- Ulrich Hoppe, University of Erlangen, Germany
- Hagen Malberg, University of Karlsruhe, Germany
- Gerhard Staude, University of the Federal Armed Forces Munich, Germany
- Andreas Voß, University of Applied Sciences Jena, Germany
- Niels Wessel, Humboldt University of Berlin, Germany
- Herbert Witte, Friedrich Schiller University Jena, Germany
- Werner Wolf, University of the Federal Armed Forces Munich, Germany.

The members of the board are indebted to all the reviewers who did a really excellent job; the list of the reviewers will be provided in the second part of the special issue. The selection of papers for this first part of the special issue predominantly reflects the traditional areas of biosignal processing: patient monitoring, ECG and EEG. Part two of the special issue will spread the focus to the huge variety of (new) applications of biosignal processing. Despite this variety, the methods are often the same but applied to different signals, which is often obscured by the dominance of the physiological and clinical background of the reports. Therefore, the task force to compile this special issue on Biosignal Processing should be continued by establishing a “Kompetenznetz Biosignalverarbeitung”, which can further enhance the progress in this interdisciplinary field and stimulate increased cooperation between research and clinical applications.

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