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Introduction. Editorial on 'Signal processing in vital rhythms and signs'

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Signal processing has become a core technology in medical devices today, as it is crucial in a wide range of applications. It is used to automate the measurement of various signal characteristics, which previously was done manually and, as a result, subjectivity is reduced and reliability is increased. Another purpose is to filter out undesired signal components of technical or physiological origin so that the signal-to-noise ratio is improved and subsequent analysis facilitated. Signal processing is also of key importance when uncovering components with low amplitude and/or subtle variations in frequency, which are very difficult, if not impossible, to observe by the naked eye. For example, signal processing plays a crucial role for the detection of the alternans phenomenon occurring during cardiac repolarization. Information about alternans has turned out to be the most useful for risk stratification of certain cardiac patients. The analysis of heart rate variability represents another application where signal processing is essential for the characterization of tiny oscillations in rhythm; the resulting measurements convey unique information about the autonomic nervous system. Considering that today's recording equipment and computers are quite powerful and available at affordable prices, limitations related to implementation are rather procedural than computational. The role of signal processing can therefore be expected to further increase in the future as novel techniques are developed and used to uncover and characterize hidden activity which may be present in a signal.

Traditionally, biomedical signal processing has been largely synonymous to 'unimodal' analysis in which only one type of signal has been subjected to analysis at a time. Countless approaches have been developed to unimodal analysis of the most common bioelectrical signals, i.e. the electrocardiogram (ECG), the electroencephalogram (EEG) and the electromyogram (EMG). However, multimodal signal modelling and processing are currently receiving considerable attention as it is highly desirable to account for the interdependence that exists between different

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One contribution of 13 to a Theme Issue 'Signal processing in vital rhythms and signs'.

physiological signals. The overall aim with multimodal signal processing is to obtain relevant information to diagnose, evaluate, monitor and eventually drive therapy. Such processing has been successfully employed in areas as diverse as the study of cardiovascular system dynamics, diagnosis of sleep apnoea and intensive care monitoring. The development of multimodal techniques comes with higher demands on the engineers as it is essential to have good understanding of different physiological mechanisms.

Research in signal processing has resulted in a great variety of linear techniques which are used in biomedical applications. Linear techniques are useful for processing activity that can be modelled as linear or almost linear, the most well known being linear filtering of an observed signal so that undesired additive components are removed. For certain types of signals it is also appropriate to apply linear system identification and to employ the resulting parameter estimates for computing parameters with clinical interpretation. However, linear techniques are not always adequate for extracting clinical information and therefore rules have been introduced that combine linear and nonlinear techniques, a simple example being the matched filter and the squaring operation found in most QRS detectors. Many physiological phenomena are inherently nonlinear and consequently require nonlinear techniques in order to provide detailed characterization. Nonlinear signal processing has received much attention in recent years and various parameters based on chaos-related studies have been suggested, e.g. the fractal dimension and sample entropy. Such parameters are useful for extracting information that remains hidden when linear signal analysis is performed. The use of nonlinear parameters will potentially strengthen the signal analysis if they are able to relate to underlying mechanisms of a physiological system. Nonlinear approaches have been considered in many applications, e.g. for the analysis of heart rate variability and for determining the organization of EEG in relation to different pathological states.

The primary aim of this special issue is to put emphasis on signal processing of vital rhythms, where the above-mentioned tendencies on integration between physiology and signal processing are taken into account. Another aim is that this special issue can serve as a reference for new researchers who want to learn more about this challenging research area. Therefore, the invited authors were requested to contribute with state-of-the-art reviews of their respective expert areas, either with the main focus on their own work or with a broader view of the area. It is our hope that this issue, together with current scientific work, will help bridge the gap between engineering and physiology so as to facilitate advances in biomedical engineering and the transfer of results to society.

The selected topics deal with bioelectrical signals as ECG, EEG, EMG, multimodal signal analysis, long-term rhythms, stationary and non-stationary phenomena and with different signal processing tools. The issue contributions are listed below.

(i) Sudden cardiac death is a challenging health problem in the Western world, and several factors are involved in the initiation and maintenance of arrhythmias which lead to sudden death. The expression of those factors, as reflected in the repolarization phase in the ECG, have been found useful for risk assessment and massive scrutiny when characterizing spatial or temporal repolarization dispersion. Pueyo *et al.* (in press) review indices derived from the ECG, their physiological correlations and signal processing implications.

(ii) Atrial fibrillation is the most commonly encountered cardiac arrhythmia in clinical practice. Sörnmo *et al.* (in press) give an overview of signal processing approaches to the extraction of atrial fibrillation activity in the presence of ventricular activity when the analysis is based on the surface ECG. Characterization of the resulting atrial signal in terms of its time–frequency properties is reviewed and the significance of the obtained information in clinical management is discussed, including the identification of pathomechanisms and prediction of therapy efficacy.

(iii) The analysis of heart rate variability is useful for exploring the autonomic nervous system and different mechanisms controlling heart rate. Mainardi (in press) focuses on variability analysis in different non-stationary situations. The classical frequency domain indices, e.g. low- and high-frequency components, are presented in the context of time–frequency analysis with applications to transient phenomena observed during ischaemic attacks, provocative stress testing and sleep or daily life activities.

(iv) Since the underlying physiological mechanisms that regulate heart rate are composed of complex networks, methods from nonlinear dynamics have been employed for the analysis of heart rate variability. In Voss *et al.* (in press), a review of some of the most prominent indices of nonlinear and fractal dynamics are summarized and their algorithmic implementation is discussed, as well as their application in clinical trials.

(v) The EEG is important when studying the brain activity. Epileptic processes are a particular application that is especially useful in drug-resistant partial epilepsy. Epileptogenic networks must be localized and understood prior to subsequent therapeutic procedure. Wendling *et al.* (in press) present signal processing techniques for extracting epileptic information from the spatial EEG properties in the time and frequency domain so that the resulting information can be put in a ‘coherent and interpretable picture’ that supports therapeutic strategies.

(vi) Hornero *et al.* (in press) explore the usefulness of nonlinear methods in patients with Alzheimer’s disease, using the EEG as well as the magnetoencephalogram (MEG). Again the complex behaviour of neural networks leads to exploring these methods to determine when this disease is developing and to facilitate its diagnosis. The paper discusses why such methods are appropriate for this type of diagnosis and shows how the EEG and MEG background activities in Alzheimer patients are less complex and more regular than in healthy control subjects.

(vii) The surface EMG contains valuable information about physiological and morphological characteristics of the active muscle and its neural strategies. However, surface EMG recordings contain noise and other artefacts. Karlsson *et al.* (in press) give an overview of signal processing methods for surface EMG analysis, and the way information about muscle activation dynamics and muscle fatigue, as well as information about single motor units (conduction velocity, decomposition and synchronization) can be extracted.

(viii) The paper by Merletti & Farina (in press) is, in contrast to the previous, dedicated to the intramuscular signals detected with needles or wires inserted into the muscle, signals that have better selectivity for individual motor unit action potentials. The state of the art decomposition of intramuscular recordings into individual motor unit action potentials is reviewed, pointing to the potential of joint use of intramuscular and surface EMG. The clinical use of intramuscular EMG signals is reviewed in the context of diagnosis of myopathies, diseases of the α-motor neuron and neuromuscular junction.

(ix) Apnoea detection is an important application of multimodal signal processing, where much effort is done to develop home-related diagnostic systems and to avoid cumbersome diagnostic units in the hospital. de Chazal *et al.* (in press) present a method that integrates information from the ECG, respiratory and oximetry recordings. The method is used to identify periods of sleep disordered breathing and to separate control subjects from subjects with clinically significant sleep apnoea using pattern recognition techniques.

(x) Porta *et al.* (in press) also deal with multimodal analysis, but for the purpose of understanding the cardiovascular control system. This leads to the study of multimodal systems that integrate the joint interaction of many signals. The importance of closed-loop identification and causal analysis is discussed as are basic properties, application conditions and methods. The need of further integration of cardiovascular signals relevant to peripheral and systemic haemodynamics, respiratory mechanics, neural afferent and efferent pathways is also stressed.

(xi) Clifford *et al.* (in press) address a different multimodal scenario, being the management of data in the intensive care unit where digital information flow has grown dramatically in recent years. The major factors affecting data quality, heterogeneities and other characteristics are reviewed. The paper describes some of the key problems and associated methods that hold promise for robust parameter extraction and data fusion for use in clinical decision support.

(xii) Fernández *et al.* (in press) deal with the study of long-term predictable changes in biological data with different frequencies, mainly, but not exclusively, along the rest–activity cycle (circadian variation). Deviations from normality can have clinical implications for, for example, drug administration. The available data series is typically noisy and sampled at non-uniform time intervals. Techniques to study such rhythms are discussed and special attention is paid to the blood pressure signal and implications on cardiovascular risk.

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