Algorithms and circuits for truly wearable physiological monitoring

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Abstract—Truly wearable physiological sensors, monitoring for example breathing or the electroencephalogram (EEG), require accurate and reliable algorithms for the automated analysis of the collected signal. This facilitates real-time signal interpretation and reduces the burden on human interpreters. It is well known that to reduce the total device power in many physiological sensors the automated analysis is best carried out using dedicated circuits in the sensor device itself, rather than transmitting all of the raw data and using an external system for the processing.

To allow the physiological sensor to operate from the physically smallest batteries and energy harvesters new algorithms optimized for low power operation are thus required. This results in designers being presented with new trade-offs between the algorithm performance (for example the number of correct detections of an event and the number of false detections) and the power consumption of the circuit implementation. This presentation explores the state-of-the-art algorithms and circuits for use in these situations, drawing on particular examples from algorithms and circuits for use in breathing monitoring and EEG analysis.

I. INTRODUCTION

In recent years there has been huge progress in the development of highly miniaturized sensors for the unobtrusive, convenient, and long term monitoring of a range of physiological parameters. This could be heart monitoring through the electrocardiogram (ECG) or pulse oximetry; brain monitoring through the electroencephalogram (EEG) or functional near-infra-red (fNIR); breathing rate monitoring; blood pressure monitoring; fall detection; or one of many others. There is now a key research challenge in moving beyond highly miniaturised devices to having truly wearable devices that become a natural part of everyday life for the user.

This transition has already started to happen for ECG applications: for example there are many amateur runners who routinely train using heart rate monitors. These devices can be set up by the non-specialist end user, and allow the user to monitor their training and improvement, and to use this information to refine their training routines.

Truly wearable physiological sensors aim to improve upon this, and moreover to provide similar functionality for more physiological parameters. This potentially involves having more connections to the body and also dealing with signals with more complex and more variable morphologies. There are thus a number of unresolved research challenges.

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II. TOWARDS TRULY WEARABLE SENSORS

From the end user perspective truly wearable physiological sensors must be: small, discrete, socially acceptable, easy to use, long lasting, accurate, and reliable. Simultaneously, from the engineering perspective there must be no compromise in the electronic and medical aspects of the device: sampling rates, signal-to-noise ratios, safety regulations and other specifications must also be met. Meeting all of these factors simultaneously requires innovations on a number of fronts. For example, on the mechanical front there are challenges in ensuring that a non-specialist user can set up a reliable and long lasting connection to the body which will have minimal motion artefacts. Alternatively, on the electronic front, it must be ensured that the sensors can operate autonomously for long periods of time from the physically smallest batteries or energy harvesters. Devices can then relied upon to always just work.

In addition, for truly wearable sensor devices automated, real-time, signal analysis is mandatory. In many analysis cases at present the gold standard for interpreting the signals produced by physiological monitors is by a trained human specialist. This takes time and resources and so becomes impossible as physiological sensors become more common and ever more physiological data is generated. Thus as wearable sensors become increasingly sophisticated and available, automated analysis becomes essential to reduce the burden on trained human interpreters and for simple tasks to allow completely automated analysis.

Importantly, this automated, real-time, signal analysis should be integrated into the wearable device itself [1]. The electronics used to implement the automated analysis algorithms therefore must have very low power consumption, again to allow operation from the physically smallest batteries or energy harvesters. This must be achieved while ensuring reliable and trustworthy operation from the signal processing and the overall device. Whereas traditional automated algorithms have considered the two-way trade-off in performance, for example between the number of correct detections of an event and the number of false detections, algorithms now have to consider the three-way trade-off, incorporating power consumption. This extra dimension provides both new challenges, for example in terms of achieving acceptably high detection performance while keeping the power consumption of the algorithms low, and also new opportunities for optimizing the entire system, for example in using the algorithms to decrease the amount of data to transmit from the sensor device, allowing a high power wireless transmitter stage to be turned off more often.
III. RELIABLE LOW POWER ALGORITHMS

This talk will overview state-of-the-art algorithms and low power electronics for providing the required signal processing. In particular, it is well known that circuit implementations using custom microchips, known as Application Specific Integrated Circuits (ASICs), offer the lowest power consumption for implementing a given function. The superior power performance is because in a custom device every aspect of the electronic circuit can be tailored for the wanted operation. However, this comes at the cost of a more complex and time consuming design, which is also more expensive. We will focus on these dedicated ASIC implementations of the required electronics [2]–[5] and provide contrast to more generic approaches based upon commercially available micro-controllers [6].

To keep the discussion tractable applications in breathing monitoring [2]–[4], [6], [7] and EEG processing [1], [5], [8], [9] will be discussed in detail. We will take an integrated approach, essential for truly wearable physiological sensors, considering all levels from the algorithm motivation and design, to the performance and reliability. We will then consider the power consumption of the required electronics, and the trade-offs with reliability as the power consumption is decreased. For example, two, supposedly identical, transistors on an ASIC will in practice not match each other perfectly, and the amount of mismatch present is a function of the average current and hence power consumption [5]. To enable truly wearable physiological monitoring systems such information from the circuit design must be built back into the algorithm design and the two topics tackled holistically. Examples of this, drawn from [4], [5], [8], will be given.

REFERENCES