Daytime monitoring of patients with epileptic seizures using a smartphone processing framework and on-body sensors

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13:00 **Telemedicine - and Fetal ECG**
Chair: Peter Veltink

13:00
15 mins

A 60 DB LINEAR INTEGRATED SUB-HZ HIGH-PASS FREQUENCY RESPONSE FOR AN EXG READOUT SYSTEM

Senad Hiseni, Rachit Mohan, Wouter Serdijn

Abstract: There is a growing need to provide personalized and preventive healthcare solutions to reduce the burden on the existing infrastructure. This requires monitoring devices to be small and hence there is a need for fully integrated ExG solutions. An important challenge in the design is integrating a large time-constant required for implementing the high-pass characteristic, needed to reject low frequency interference such as baseline wander. For example, for an electrocardiography (ECG) device, the high-pass cutoff frequency is usually specified to be < 1 Hz [1]. Moreover, a resolution of at least 10 bits is required to detect low amplitude signal variation [2]. Pseudo-resistors are widely used to integrate large time constants. However, they are inaccurate as their resistance is determined by leakage currents and they are also non-linear as the resistance depends on the voltage across them. Since the cutoff frequency will vary with the momentary value of the input voltage, there will be distortion near the cutoff frequency, thereby limiting the resolution for frequencies in that region. The switched capacitor technique can also been used for obtaining large time-constants. It is more accurate than pseudo resistors. However, it will require high capacitor ratios and very low frequency clocks to achieve such a low cut-off frequency. Moreover, an anti-alias filter will also be needed which increases the overall system power. Recently a mixed-signal feedback technique has been used to implement the high-pass characteristic [3], [4]. In this technique the signal is processed in the digital domain and fed back to the previous analog stage to achieve the required frequency characteristic. It utilizes the fact that in general, the objective of any front-end is to convert the physiological signal in to a digital one. Filtering can, in principle, be done in either the digital or the analog domain. The choice for an analog or a digital filter would depend on the power budget and the DAC resolution. In [3] and [4] a 7-bit signal converted from a 8-bit one and a 1-bit signal converted from a 12-bit one, respectively, are used to obtain a low cut-off frequency. In both cases, similar to pseudo-resistors, the linearity of the signal near the cut-off frequency will be limited. This paper proposes an ExG front-end with a 10-bit linear high-pass response using the mixed-signal feedback technique along with a $\Sigma\Delta$ ADC. Instead of feeding back the fully converted digital signal, the output of the $\Sigma\Delta$ modulator is fed back via a 1-bit DAC and an analog filter. Since a 1-bit DAC is inherently linear, the overall resolution and linearity depend on the oversampling ratio, the order of the $\Sigma\Delta$ modulator and the linearity of the filter in the feedback path, which can be designed to obtain the desired linearity.

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15 mins

AN LOW NOISE AMPLIFIER WITH OPTIMALLY MISMATCHED ANTENNA INTERFACE FOR WIRELESS IN-BODY AREA NETWORK APPLICATIONS

Yao Liu, Wouter Serdijn

Abstract: Radio frequency (RF) powered sensor devices have gained more and more interest in wireless in-body area network (IBAN) applications. In contrast to a device powered by a battery with limited lifetime, an RF powered device has "unlimited" lifetime since it extracts power from propagating radio waves. The RF powered sensor device is often used in applications such as implantable medical devices where battery replacement is impossible without surgery. Besides a data link, the RF powered sensor device also has a wireless energy link enabled by an RF energy harvester. Nowadays, the energy link [1] and data link [2] are mainly optimized separately. Only a few papers discuss their system level integration [3]. In these systems, the two links are effectively decoupled by employing two different frequency bands, but demanding two bulky antennas and associated external matching components, thereby limiting the size reduction of the whole sensor device. Sharing the same antenna between an energy link and a data link is necessary to reduce the size of the RF powered sensor device dramatically, but presents some design challenges at the interface of the antenna, energy harvester and the first stage of the receiver, i.e., low noise amplifier (LNA). The antenna interface of an energy harvester is usually optimized to increase the available input voltage by a voltage-boosting network [1]. However, an LNA interface is usually designed for a 50Ω resistive input impedance, which is not optimized for the voltage-boosting network and will reduce the passive gain of the network considerably. Moreover, a 50Ω impedance requirement adds an important constraint on the LNA design, thereby restricting the performance and power reduction of the LNA. Taking into account the extremely limited power budget, this limitation is more severe in RF powered IBAN devices. This paper presents an optimally mismatched antenna interface and an LNA based on this interface for the combination of the energy harvester and the LNA. The interface offers large passive voltage boosting to improve the voltage gain and NF of the LNA in a low power environment, and increases the sensitivity of the energy harvester as well. The interface and LNA have been designed at circuit level and verified with simulations in AMS 0.18μm IC technology. A comparison with another LNA design based on a standard 50Ω power matched interface shows the proposed LNA has 12.3dB higher voltage gain and 1.8dB lower NF at a power consumption of only 50μW.

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15 mins

COMBINING HEART RATE AND ACCELEROMETER DATA TO ESTIMATE PHYSICAL FITNESS

Thijs Tönis, Miriam Vollenbroek-Hutten, Hermie Hermens

Abstract: Monitoring changes in physical fitness is relevant in many conditions and groups of patients, but its determination demands substantial effort from the person, personnel and equipment. Besides that, present (sub) maximal exercise tests give a momentary fitness score, which depends on many (external) factors. Obtaining a fitness score based on measures gathered during longer periods of time and in natural conditions, like in daily life, would be an attractive alternative for the present methods. We performed an explorative lab-experiment to study the feasibility of fitness estimation during an activity commonly encountered in daily life; walking. PURPOSE: To investigate the feasibility of physical fitness estimation from combined heart rate and accelerometer data obtained during treadmill walking. METHODS: Forty-one subjects (23m, 18f) aged between 21 and 29 walked at three speeds on a treadmill (4, 5.5 and 6 kmh-1) wearing a heart rate monitor and a hip mounted 3D accelerometer. The acceleration signal was converted into activity counts [1] per 10 seconds. Stepwise linear regression analysis to estimate VO2max was performed on the slope and intercept of the linear relation between heart rate and activity counts during steady state exercise (> 3min), together with age, gender, weight, length and BMI. Reference VO2max was obtained by performing a sub-maximal single stage treadmill walking test [2]. RESULTS: The model with the highest percentage of explained variance (R2=0.93) combined the slope and intercept parameter of the relation between heart rate and activity counts, together with gender. The model had a standard error of the estimate of 1.78 ml O2kg-1min-1. DISCUSSION: Results of the model are comparable with commonly used submaximal laboratory tests to estimate VO2max. Fusing heart rate and accelerometer data during steady state activities seems promising for ambulant estimation of VO2max and would not require the subject to carry out a high performance test. The applicability of current method on a broader age group and in daily life is part of ongoing research.

13:45
15 mins

DAYTIME MONITORING OF PATIENTS WITH EPILEPTIC SEIZURES USING A SMARTPHONE PROCESSING FRAMEWORK AND ON-BODY SENSORS

Frank Roberts, Gabriele Spina, Constantin Ungureanu, Oliver Amft

Abstract: Patients suffering from epileptic seizures face various difficulties in daily life. In particular, major seizures may lead patients to remain unconscious and thus could result in accidents and situations, where the patient needs external help. Various approaches have been made to build sensor-based monitoring solutions to determine seizure events, e.g. [1, 2]. Most approaches used a single modalities based on physical acceleration of limbs or measured heart activity, which often results in seizure detection errors. In contrast, home monitoring systems, e.g. based on video cameras, cannot cover activities outside and typically have high cost and maintenance needs. Smartphone-based activity monitoring could provide important advantages for a daytime seizure monitoring system: a smartphone could be worn by the patient with additional ubiquitous sensors placed at relevant body positions. By combining the different information sources, the system could robustly identify seizure events, potentially calling for assistance and providing seizure statistics to caregivers. However, existing smartphone-based sensor data processing solutions are highly limited in the type of sensors and algorithms that can be used. Thus patients cannot choose and interoperate sensors, and systems cannot be personalized according to patient needs. In this work we present a new unobtrusive, long-term monitoring system running on Android smartphones that integrates multiple sensing modalities especially suitable for seizure detection. It uses an open source toolbox [3] as processing component to rapidly prototype different classification algorithms. Our system uses a configurable architecture that already supports several sensors from different manufacturers besides different wireless communication protocols (Bluetooth, ANT, etc.) and real-time visualization of the streamed data and results. Due to the low frequencies of epileptic seizures in patients during daytime, the developed framework has been evaluated in a case study where expert actors were asked to simulate epileptic seizures during selected everyday activities such as walking, brushing teeth, shaking hands. In this study an inertial motion sensing unit [4,5] was placed on the wrist and ECG electrodes [4] at the chest. Data were analyzed and used to train a classification algorithm running in real-time on the smartphone. We present in this work our first performance results of using the smartphone-based system for epileptic seizure detection. Our initial tests showed that our framework in combination

with the additional multimodal on-body sensors can be used as a flexible choice for recording and detecting epileptic seizures during daytime. While recording acted seizures was sufficient for this initial evaluation of the system, we plan to use the system with patients in the future.

14:00 **PROBABILISTIC SOURCE SEPARATION FOR ROBUST FETAL ECG ANALYSIS**
15 mins *Rik Vullings, Massimo Mischi*

Abstract: Blind source separation (BSS) techniques are widely used to extract signals of interest from a mixture with other signals. For example, BSS techniques have been used to retrieve fetal electrocardiogram (ECG) signals from non-invasive recordings performed on the abdomen of a pregnant mother, although with moderate success. One of the reasons for this moderate success is the typically low signal to noise ratio (SNR) of the fetal ECG in the abdominal recordings. As a result, BSS techniques often prioritize other sources, like maternal ECG, muscle activity, and noise, over the fetal ECG [1]. This lack of robustness against poor SNR can be (partly) overcome by incorporating a priori knowledge on the mixing of the source signals. Particularly for electrocardiographic signals, knowledge on the mixing process is available in terms of existing models of the origin and propagation properties of the ECG signals. Unfortunately, virtually none of the available BSS techniques allows for the incorporation of such a priori knowledge. In this study, a novel source separation method is developed that combines the potential accuracy of BSS techniques, in particular independent component analysis (ICA), with the robustness of an underlying physiological model of the electrocardiogram (ECG). The method is developed within a probabilistic framework and yields an iterative estimation of the separation matrix towards a maximum a posteriori solution, where in each iteration the separation matrix is corrected towards the physiological model. The degree of correction is hereby governed by the SNR, providing a flexible trade-off between robustness and accuracy; In case of low SNR, the physiological model contributes more to the estimate of the separation matrix. In case of high SNR, the ICA contributes more to the estimate of the separation matrix. The developed source separation method is evaluated by comparing its performance to that of FastICA [2] on both simulated and real multi-channel ECG recordings. The simulated recordings provide a means for quantitative evaluation and show a 20% decrease in the mean squared error between original ECG sources and retrieved sources for the developed method, with respect to FastICA. As for real data, source separation has been applied on abdominal fetal ECG recordings with the goal of finding a fetal ECG source of sufficient SNR to allow for fetal heart rate detection; The developed source separation method succeeded, while the BSS method did not. Future work includes more extensive evaluation of the developed method as well as further enhancement of the retrieved fetal ECG to allow for the use of fetal ECG in obstetrical diagnostics. REFERENCES [1] S. Harmeling, F. Meineck, K.-R. Müller, “Analysing ICA components by injecting noise”, 4th International Symposium on ICA and Blind Signal Separation, pp. 149-154, 2003. [2] A. Hyvärinen, “Fast and robust fixed point algorithms for independent component analysis”, IEEE Trans on Neural Networks, Vol. 10(3), pp. 626-634, 1999.

14:15 **SELECTION OF OPTIMAL ELECTRODE POSITIONS FOR AMBULATORY PREGNANCY MONITORING**
15 mins *Michiel Rooijakkers, Chiara Rabotti, Massimo Mischi*

Abstract: Non-invasive pregnancy monitoring has become increasingly relevant in order to prevent complications. Fetal heart-rate (fHR) monitoring and estimation of uterine activity are important means to assess fetal health during pregnancy and delivery. Recent advances in signal processing technology enable pregnancy monitoring using abdominal electrocardiogram (ECG) and electrohysterogram (EHG) recordings [1], [2]. The large number of electrodes required in current noise-robust solutions, however, leads to high power consumption and reduced patient comfort, hampering unobtrusive ambulatory monitoring. To enable pregnancy monitoring in an ambulatory setting, the number of electrodes has to be reduced without compromising signal quality. Therefore, the influence of abdominal electrode positioning on the SNR of various signals of interest for pregnancy monitoring is explored based on measurements. Three measurements on women at full gestation just prior to labor (w39d4 ± 12d), with a total length of 1 hour, were performed using an electrode grid consisting of 12 electrodes. The electrodes are organized in a triangular fashion, which allows for analysis of the recorded signals in six different directions at three different inter-electrode scales, resulting in a total of 18 bi-polar signals for each measurement. To define the ability of all electrode pairs to capture the electrophysiological characteristics of interest, a signal quality criterion for both the fetal and maternal ECG as well as the EHG is defined based on the SNR. The SNR of both ECG signals is defined as the power of the QRS segment divided by the RMS power of the remaining signal. In case of the fetal ECG (fECG), the maternal ECG (mECG) was first removed using the method described in [1]. For the EHG, the signal and noise power are defined as the RMS signal in the 0.34 – 0.8 Hz frequency band in time segments during and in between contractions, respectively. Results show that the SNR of both the fetal and maternal ECG increasing with increase inter-electrode distance and are strongly dependent on measurement direction. In the case of mECG, a horizontal measurement orientation is preferred, while the optimal measurement direction for fECG changes depending on the orientation of the fetus with respect to the electrode grid. Contrary to the ECG, the SNR of the EHG shows an optimum for an electrode distance of 8 – 12 cm, while the optimal electrode orientation changes for every contraction. An electrode grid allowing for optimal detection of both ECG and EHG signals, therefore, should contain inter-electrode distances of both 8 and 16 cm with various orientations. According to our results, a triangular measurement setup with 6 electrodes, therefore, enables recording of mECG, fECG, and EHG signals with a SNR of 12.3 dB, 6.1 dB, and 9.8 dB, respectively.

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