BIOELECTRIC ACTIVITY RECORDING BASED ON A SINGLE ELECTRODE FOR USE ON WEARABLE DEVICES

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Abstract: Wearable devices are used to unobtrusively record several physiological signals. Bioelectric signals are one of the most important variables monitored. Despite the available techniques, including capacitive coupling, it is still lacking a contactless solution that can be integrated into wearable devices. We propose a new approach where an instrumentation amplifier is directly driven by a bioelectric signal. In this way, the voltage drop on the capacitive electrodes is avoided. In this paper we show the proof of concept, and results are presented to show how to record an Electrocardiogram (ECG) using this new approach. Measurements were made using a high-impedance instrumentation amplifier. Results have shown that our approach is viable for bioelectric signal detection using contactless methods.

1 INTRODUCTION

Advances in electronic, textile and information technologies have contributed to the design of wearable monitoring systems, aimed to provide continuous, unobtrusive and remote monitoring of physiological signals. An important contribute is made by novel technologies for detecting bioelectric signals. Not every sensor can be used in a wearable context and a set of attributes must be taken into account. These include physical attributes such as size and weight, as well as easy placement and an unobtrusive aspect. In addition, wearable sensors must ideally produce an electrical output in order to be digitally processed. Properties such as durability, reliability and low power consumption are also demanded (Constantine and Fotiadis, 2005) (Winters and Wang, 2003). Acquisition devices are based on contact or contactless measurements. Focusing on the first type, two main options arise: dry or wet (require gel) electrodes. There are some semi-invasive solutions available, where the electrodes are based on micro spikes that go trough the skin (Ng et al., 2009). On the other hand, with contactless measurements, the available solutions consist in the use of a capacitive or inductive coupling, and also the use of electro-active materials (e.g. electro-optic material). However, since they use electrodes to drive the signal, a significant potential drop occurs, causing difficulties in the detection of smaller signals such as brain electric activity.

The focus of this work consists in proposing an approach towards contactless detection of bioelectric signals. In this paper we will demonstrate the concept of the non-contact acquisition of bioelectric signals, using the bioelectric field to directly drive an instrumentation amplifier, instead of the conventional use of big capacitive electrodes. This will significantly benefit the design of contactless bioelectric sensors particularly for wearable applications. The experimental setup used to the proof of concept of our approach will be described as well as the results obtained.

2 CONTACTLESS MEASUREMENT

The need for physical contact has for long been a problem when envisioning a wearable monitoring application. Ideally, a biopotential recording system should draw no real charge current from the body, allowing to perform non-contact measurements of biopotentials. However, the present solutions imply a voltage drop across the electrode, either wet, dry or capacitive, limiting the sensitivity and ability to provide efficient contactless measurements. When looking into the wearable matter, the standard

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solutions show two main problems: they are difficult to integrate with the vests and uncomfortable to wear. A new generation of sensors is required in order to surpass the limitations of the present solutions.

We propose a new approach for contactless detection of biopotentials that avoids the voltage drop by directly driving an instrumentation amplifier with a bioelectric signal. The input impedance of the instrumentation amplifier should be as high as possible in order to allow the remote detection of biopotentials. Moreover, input technologies based on Complementary Metal–Oxide–Semiconductor (CMOS) and Field-Effect Transistors (FET) should be used since they are driven by voltage instead of current. In our approach there's only one contact with the subject skin, responsible for establishing a reference signal – reference electrode. In this way, bioelectric signals will be simultaneously measured without any contact at the recording locations, sharing the same reference.

We are particularly envisioning the application of this approach in brain biopotential wearable systems. The existent solutions are not suitable for use in fully wearable devices. With our approach, we hope to contribute to the design of appropriate wearable sensors for further applications in relevant areas such as Brain-Computer Interface (BCI). Figure 1 shows an example of application of our contactless approach in Electroencephalogram (EEG) wearable recordings, where the sensor would be placed close to the scalp. One of the inputs is connected to the contact reference electrode. The other is floating in order to drive the instrumentation amplifier with the bioelectric signal.

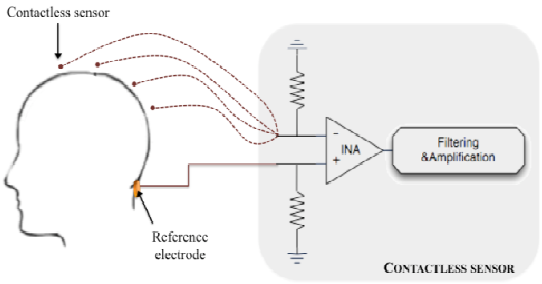

Figure 1: Contactless sensor for biopotential acquisition. Dashed lines are used to indicate that the sensor may be placed in several recording locations.

The standard setups use the ear lobes as a reference signal, since there's minimal influence of temporal lobe or muscle electrical activity. However, from a user perspective, it would be preferable to place the reference in a more discreet place, since the main objective of wearable systems consists in providing ubiquitous monitoring in daily life activities. Therefore, we propose to place the reference electrode on the back neck, establishing the only contact with the skin. The recording sensors are placed near the target locations, without any kind of contact with the scalp.

3 BIOELECTRIC SIGNALS

3.1 Signal Characterization

Bioelectric signals are recorded as voltages, potentials and electric field strengths, at very low levels, with high source impedances and overlaid interference signals and noise. They can be classified according to the type of cells and tissue they are originated from. Table 1 lists the most relevant biopotentials along with its properties (Webster, 1988).

Table 1: Properties of Biopotentials (ECG – Electrocardiogram; EOG – Electrooculogram; EMG – Electromyogram).

Biopotential	Tissue	Amplitude	Frequency
ECG	Heart	1-5 mV	0.05-100 Hz
EEG	Brain	10-200 μV	0.5-40 Hz
EOG	Retina	0.01-0.1 mV	dc-10 Hz
EMG	Muscles	1-10 mV	20-200 Hz

It's important to note that due to several constrains resultant from travel and propagation (e.g. tissue resistivity), detected properties such as amplitude and shape will be very distinct from those detected inside the specific tissue that originates the bioelectric event.

3.2 Standard Readout

The three essential components required to measure a bioelectric signal are: bioelectrodes, instrumentation amplifiers and filtering components (Neuman, 1998). On the process of sensing a biopotential, it is required to provide some interface between the body and the measuring device. This interface is carried out by bioelectrodes that convert the ionic current within the body into electronic current in metal connecting leads (Neuman, 1998). Bioelectrodes should have low impedance. Otherwise the currents driving the subsequent amplifier will lead to a biopotential drop, leading to

more difficult readouts. Three types of interface between the electrode and the skin can be applied: wet, dry/insulated and capacitive coupled. The first one makes use of an electrolytic gel that helps to promote the reduction of the contact impedance, minimizing the risk of signal loss. This carries time-consuming and complex procedures. The most commonly used wet bioelectrode is the gel type silver/silver chloride (Ag/AgCl), which can be found both in reusable or disposable form. Dry and insulated electrodes eliminate the need for an electrolytic paste. The first type consist of a biocompatible metal in direct contact with the skin, being the coupling between them made by the user's sweat produced after it's placement. On the other hand, insulated electrodes are based on a dielectric surface layer between the metal or semiconductor and the skin. In this case, the bioelectric signal is capacitively coupled between the skin and electrode, without requiring electrical contact with the skin. Some examples of dry/insulated electrodes and their application can be found in (Baek et al., 2008; Ryu et al., 2005). The third type of interface requires no physical contact with the skin and it's based on capacitive pick-up electrodes. Basically, the biopotential is obtained by capacitive coupling between the body and the electrode, working both as plates of a capacitor (Harland et al., 2002).

Bioelectric signals need to be amplified in order to make them compatible with a variety of devices such as A/D converters or display equipments. The instrumentation amplifier is commonly used to record biopotentials since it fulfils the basic requirements for biopotential amplifiers, being designed to have extremely large input impedance and a small bias current. It works as a differential amplifier, by applying high gain amplification between signals at the positive and negative inputs. Since the input signal of the amplifier consists of the desired bioelectric signal and unwanted components (e.g. power line interference signals, noise, etc.), it is crucial to include a filtering stage. Generally, a notch filter centered at 50 Hz (60 Hz in USA), and a bandpass filter are used to remove these unwanted signal components, that sometimes have higher amplitudes than the desired bioelectric signal.

4 MEASUREMENTS

Measurements were carried in order to demonstrate the concept of biopotential contactless recording. The proof of concept consists into two stages: the first experiment uses a conventional instrumentation amplifier with subsequent filtering and amplification stages; then, the resultant filtered and amplified ECG is directly and contactless driven into a FET-input instrumentation amplifier.

4.1 Experimental Setup

The modules used to validate our approach for contactless detection of bioelectric signals include: instrumentation amplifiers, notch filters, band-pass filters and voltage amplifiers. The type of amplifiers used, instrumentation amplifiers, need to fulfil a particular set of requirements in order to provide selective amplification to the biopotential, rejecting the superimposed noise and interference components:

- Have high input impedance (at least 10 MΩ) and electrical isolation in order to inhibit interference or distortion of the recorded signals.
- High CMRR (>80 dB according to (Neuman, 1998)) in order to separate as much as possible the relevant signal from noise and interferences;
- Supply enough gain within its bandwidth in order to reach an output level compatible with the remaining system.
- Have low output impedance and supply the amount of current necessary to the load.
- Provide protection to the patient from any hazard of electrical shock.

Figure 2 shows the first module used in the carried experiments.

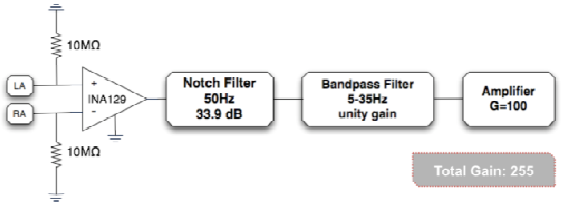

Figure 2: First module comprising a conventional acquisition circuit for biopotentials. LA corresponds to Left Arm, and RA to right arm.

At this stage, an electrode was placed on each arm, according to Lead I of Einthoven's triangle, resulting in a differential recording. The electrodes were connected to both inputs of a precision instrumentation amplifier (INA129, Texas Instruments) with an input capacitance of 2 pF ($10^{10}\Omega$) and a CMRR of 125 dB. The gain of the amplifier was set to 155, by placing an RG of 320 Ω. Since electrical circuits are usually interfered by ac power lines, a notch filter was used to remove this 50 Hz interference, with an attenuation of 33.9 dB.

To remove other unwanted signal components such as other bioelectric signals or movement artefacts, we designed a bandpass filter with unity gain and a bandwidth set according to the frequency components of interest (see Table 1). After the filtering components, the ECG signal drives an amplification stage with a gain of 100. The total gain of this module is 255.

The second stage implements the contactless module and consists of directly driving a FET-input instrumentation amplifier, by placing an isolated wire loaded with the resultant bioelectric signal from the first stage. Figure 3 depicts the contactless module of the experiment.

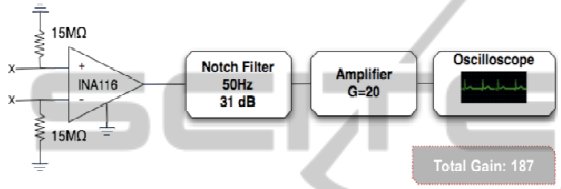

Figure 3: Contactless module comprising a conventional acquisition circuit for biopotentials (x = No connection). The ECG signal is used to directly drive the INA116 with an isolated probe.

The bioelectric signal was directly and contactless coupled by placing an isolated wire 1 cm above a FET-input instrumentation amplifier (INA116, Texas Instruments) with an input impedance of 0.2 pF (10^{15} Ω) and a CMRR of 94 dB. The signal was further amplified with a gain of 20.

4.2 Results

Experiments were carried out in order to test the recording of bioelectric signals with no contact with the skin, neither electrical nor mechanical. Fig. 4 shows the bioelectric signals recorded at the end of the first stage.

A first view of Fig. 4 allows to point some of ECG components, including the P wave, QRS complex and the T-wave. Each one corresponds to a specific electrical event that occurs during heart activity, for instance the QRS complex occurs as the ventricles depolarize. The average signal amplitudes reached a value of 3 V, after a 255 total gain.

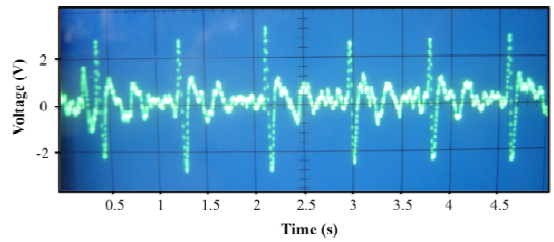

Figure 4: ECG signal obtained at the end of the first circuit module. The average amplitude of the signal is 3 V.

This signal is further used for contactless driving the INA116, using an isolated probe placed at different distances. To test the distance influence, we varied the distance between the probe and the instrumentation amplifier. Initially, the probe was placed in external contact with the INA116, and then went up to a 10cm distance. Figure 5 shows the ECG signal strength obtained for the different distances used.

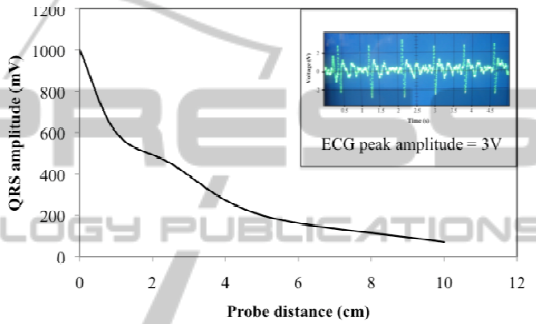

Figure 5: QRS peak amplitude versus distance between the instrumentation amplifier and the probe. The values represent peak-to-peak amplitudes. The inset represents the signal which is directly coupled from the probe to the INA116.

These results demonstrate a decrease in signal strength, as the distance between the INA116 and the probe increases. Above 10 cm, the signal becomes smaller than the noise components, causing difficulties to isolate the relevant bioelectric signal from the noise and interference. In figure 6 we show an ECG recorded at a distance of 1cm from the INA116.

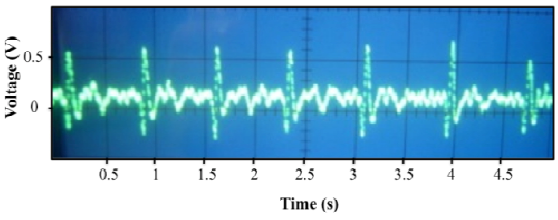

Figure 6: ECG signal recorded at a distance of 1cm from the INA116. An isolated probe was used to carry the signal from the first module. The average amplitude is 600 mV.

As shown in fig. 6, we can easily identify the QRS complex, and part of the T-wave. The periodic pattern displayed is similar to the conventional ECG detected in the first module (Fig. 4). In terms of amplitudes, the signal reaches a maximum of 600 mV. When envisioning wearable devices, ensuring a good sensor performance at a distance of 1 cm is desirable.

5 CONCLUSIONS

The developments described here open a new approach to non-contact recording of bioelectric signals, with promising applications in wearable systems. A method for testing non-contact acquisition of biopotentials by directly driving an instrumentation amplifier with a previously amplified and filtered ECG signal was proposed. Measurements were made using a high-impedance FET-input amplifier (INA116) and an isolated probe, varying the distances between them. We tested the performance of this approach in these conditions, and results have shown the possibility of successfully contactless acquire a readable ECG until 10 cm of distance from the source, suggesting that these approach could be used in bioelectric wearable sensors.

Future work is needed towards the improvement of sensitivity and noise reduction. This can be achieved by increasing the input impedance and the CMRR. The first one will result in smaller attenuation of the electrophysiological signal. A higher CMRR improves a better separation of the relevant signal from noise and interferences. The gain of the system can be easily set to higher values by changing the feedback resistor of the amplifier.

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