EXPERIMENTAL APPARATUS FOR FINGER ECG BIOMETRICS

Renato Lourenço[1], Paulo Leite[1], André Lourenço[1,2], Hugo Silva[2,3], Ana Fred[2] and David Coutinho[2,4]
[1]*DEETC, ISEL-IPL, Lisbon, Portugal*
[2]*Instituto de Telecomunicações, IST-UTL, Lisbon, Portugal*
[3]*PLUX - Wireless Biosignals, S.A., Lisbon, Portugal*
[4]*Centro de Cálculo, ISEL-IPL, Lisbon, Portugal*

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Abstract: Current Electrocardiographic (ECG) signal acquisition methods are generally highly intrusive, as they involve the use of pre-gelled electrodes and cabled sensors placed directly on the person, at the chest or limbs level. Moreover, systems that make use of alternative conductive materials to overcome this issue, only provide heart rate information and not the detailed signal itself. We present a comparison and evaluation of two types of dry electrodes as interface with the skin, targeting wearable and low intrusiveness applications, which enable ECG measurement without the need for any apparatus permanently fitted to the individual. In particular, our approach is targeted at ECG biometrics using signals collected at the hand or finger level. A custom differential circuit with virtual ground was also developed for enhanced usability. Our work builds upon the current state-of-the-art in sensoring devices and processing tools, and enables novel data acquisition settings through the use of dry electrodes. Experimental evaluation was performed for Ag/AgCl and Electrolycra materials, and results show that both materials exhibit adequate performance for the intended application.

1 INTRODUCTION

Electrocardiography (ECG) is the recording of the electrical activity of the heart over time, by means of adequate signal acquisition and conditioning electronics. These signals have found application in a variety of fields, from healthcare and quality of life (Dubin, 2000) to security (Lourenço et al., 2011b).

The acquisition of ECG signals is typically performed on the chest with pre-gelled electrodes, which is an intrusive placement as it requires the subjects to expose an intimate part of their body. For clinical applications, such a setup is accepted by the person due to the added value that it introduces in assessing the health conditions; however in applications such as biometric recognition this is not the case.

For heart monitoring during leisure and sports activities, state-of-the-art systems already use alternative conductive materials for increased usability. Nonetheless, current devices only provide heart rate information; furthermore, sensors are typically designed to be in contact with the subjects chest, or snapped to the limbs.

On the overall, for applications within the biometric recognition realm, conventional methods are either unpractical and limiting for regular use in extended periods, hindering the adoption in everyday life, or do not provide sufficiently detailed information.

Hence, our work was motivated by the need of finding alternative types of measurement settings, that (a) do not require gel to perform an adequate interface with the skin, (b) use a more convenient acquisition location with limited intrusiveness, potentiating the use of ECG biometrics for authentication purposes (Lourenço et al., 2011c; Silva et al., 2007; Shen, 2005).

Our approach targets the reduction of the intrusiveness that traditional systems introduce, by requiring access to concealed parts of the body, or having cables connected to the subject. The goal is to bring ECG acquisition apparatuses to the level of acceptability found in commercial biometric systems, and more traditional modalities (Jain et al., 2007; Ross et al., 2006; Jain et al., 2005).

In this paper, we present a hardware setup and comparison of dry Ag/AgCl electrodes and Electrolycras, a type of fabric with conductive properties. The purpose is to evaluate the quality of ECG signals acquired at the hand palms and fingers, as well as the possibility of using only two measurement leads to-

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gether with non-gelled interfaces with the skin, in a setup with which the person can easily interact with.

The rest of the paper is organized as follows: Section 2 briefly describes the current approaches to ECG signal acquisition; Section 3 introduce the proposed approach; Section 4 describes the experimental evaluation; Section 5 presents a brief discussion on the outcomes of our work; and Section 6 outlines the main findings and conclusions.

2 RELATED WORK

Clinical grade ECG signal measurement methods are based on the acquisition of signals from 12 or more leads mounted on the chest and limbs, with pre-gelled electrodes or conductive paste to improve conductivity with the skin (Chung, 2000).

New developments in signal acquisition technologies have greatly improved usability, and several systems already exist that have sensors integrated in a more convenient way, that enable the monitoring of the cardiac function without the need for conductive gel.

In (Gamboa et al., 2010), a device is described which uses Ag/AgCl electrodes, and that can be placed around the subjects neck for heart rate measurement. (Chou et al., 2006) describe a capacitive sensor that can be attached to a t-shirt to measure the ECG. A smart t-shirt was introduced by (Cunha et al., 2007), which integrates the standard measurement leads in the fabric, as a way of achieving a more practical acquisition setup.

Also in commercial systems for sports and leisure activities, an effort has been seen to improve over standard clinical setting practices. In the portfolio of (Polar Electro, 2011), conductive rubber and conductive fabric based chest strap options can be found; more recently, (EA Sports Active, 2011) has launched a wearable armband. Nonetheless, in these cases the full ECG readings are not accessible.

Current techniques require the application of the sensing apparatus to the subject's body, which in some cases involves the placement of multiple sensor leads. The existing less intrusive hardware devices only provide information about the subjects heart rate.

For biometric purposes, not all application scenarios cope well with these requirements. Targeting a real-world usage scenario, the signal acquisition must be performed in more convenient ways, which led us to the development of an alternative solution.

3 PROPOSED APPROACH

For biometric applications, subjects are already familiar with commonly used modalities, which require some degree of contact and proximity to the sensoring device. These include fingerprint (Jain et al., 2004), where the subject needs to place or scroll the finger on the reader, and hand geometry (Ross et al., 2006), where the subject needs to place the hand on the reader.

We propose an experimental apparatus for ECG biometrics, that matches the usability and intrusiveness levels of conventional biometric systems. Our device is comprised of a surface with integrated electrodes and signal conditioning circuitry, where the subject rests his/her hand palms, enabling the signal acquisition without the need for conductive gel nor access to more intimate parts of the body.

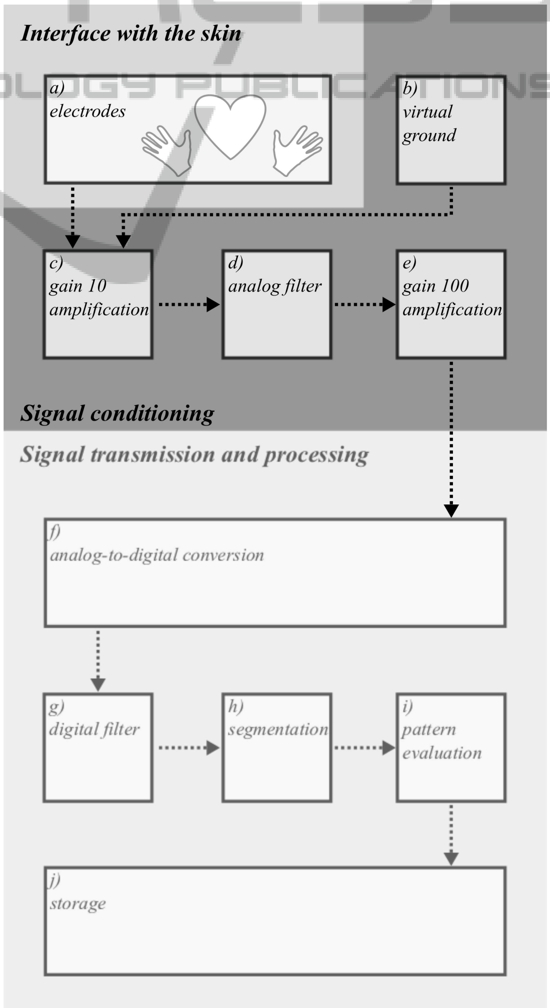

Figure 1: Block diagram of the proposed solution.

The proposed system can either be used with dry Ag/AgCl electrodes or Electrolycras as interface between the sensor and the skin, for improved usability. The former are based on conventional electrodes used for clinical ECG acquisition; the later are generally used in Faraday shields, and exhibit a surface resistivity $< 0.5\Omega/\Box$ when unstreched.

A custom signal conditioning circuit was developed, which only requires two contact points with the skin, through the use of a virtual ground circuit. This design improves upon existing sensors (Webster, 1998), as traditional ECG sensors require positive (+) and negative (-) poles, together with a ground (GND) lead. With our design, only the (+) and (-) leads are required.

The virtual ground is generated using the positive (V_{CC}) and negative (V_{SS}) supply voltage of the circuit to which the sensor is connected. A voltage divider creates an intermediate voltage between these two, which is taken as the common mode voltage of the body in the remaining amplification and filtering circuitry; a unity gain buffer was added for increased stability of the generated signal.

Figure 1 depicts the block diagram of the proposed approach with: a) the electrodes that provide the interface with the skin; b) the virtual ground generation circuit; c) first stage of signal amplification with gain 10; d) analog band-pass filtering in the 1-30Hz range; and e) second stage of signal amplification with gain 100.

Although the remaining steps fall outside the scope of this paper, the analog signal is then fed to the digital conversion and transmission chain, comprised of: f) analog-to-digital conversion; g) digital filtering; h) heartbeat waveform segmentation; i) pattern evaluation; and j) storage at the base station.

Figure 2, depicts the proposed setup. In the proposed configuration, and for experimental validation purposes, the device allows the acquisition of ECG signals at the hand palm, through dry Ag/AgCl electrodes, and at the index and middle fingers through Electrolycras.

4 EXPERIMENTAL EVALUATION

To evaluate the experimental setup, we performed an extensive data collection in 31 subjects (24 males and 7 females) with an average age of 31.1±9.46 years. Subjects were only asked to rest their left/right hands as indicated in the device.

Two custom ECG sensors were used for signal acquisition, with a total gain of 1000, and analog band pass filtering between the 1-30Hz range. In

Figure 2: Experimental apparatus: at the top, Electrolycras enable the acquisition of ECG using the index and middle fingers; at the bottom, dry Ag/AgCl electrodes acquire ECG at the hand palms.

Figure 2 both sensors are visible, one connected to the Ag/AgCl electrodes, and another connected to the Electrolycra strips placed at the index and middle finger level.

To guarantee electrical insulation of the sensors, in order to avoid ground coupling, two independent biosignal acquisition units were used, one per sensor. We recurred to the bioPLUX research system (PLUX, 2011), which enables Bluetooth wireless transmission of the collected signals to the base station. Data was acquired at 1000Hz sampling rate and with 12-bit resolution.

Synchronization of the acquisition units was performed optically using a syncPLUX kit and a light-dependent resistor (LDR). To one of the systems a triggering switch was connected, which simultaneously activated the digital input port of the system and an LED.

To the other system, a LDR was connected to one of the analog input channels, and placed in direct contact with the LED of the first system, in such way that a synchronization signal was obtained whenever the LED was lit.

This allowed us to have the data collected by each system synchronized, without recurring to any electrical connection between them. Signals were acquired during a period of approximately 2min, in which the supervisor in charge of the experimental procedure would describe the experiment, goals and related work.

We evaluated the signal-to-noise ratio (SNR) for each individual signal; a 6th order butterworth digital

Table 1: Experimental results for ECG sensor data collected using the proposed approach.

Type of Electrodes	SNR [dB] $\mu \pm \sigma$	MSE Raw/Filt. $\mu \pm \sigma$
Ag/AgCl	-3.94 ± 6.24	0.60 ± 0.20
Electrolycra	-3.15 ± 4.65	0.60 ± 0.18

filter was used, for which we considered the 2-30Hz bandwidth as the signal, and the remainder as noise. The mean squared error (MSE) was also computed to provide additional insight regarding the morphological difference between the raw and filtered signals for each type of electrode. This metric can be used as a correlation indicator, as it is zero when both signals possess an exact match.

Results are summarized in Table 1, and Figure 3 shows a segment of collected signal for one of the individuals, at the hand palms using dry Ag/AgCl electrodes, and at the fingers using Electrolycras. Although high frequency noise is noticeable in the raw data, digital filtering is able to enhance the signals, as shown in Figure 4.

As we can observe, numerical analysis revealed that dry Ag/AgCl electrode and Electrolycras exhibit a comparable performance; signals acquired with both electrodes exhibit similar levels of detail. Although the P wave is masqueraded by baseline noise, the QRS-T complexes are clearly noticeable, and the heartbeat waveforms morphology show identical behaviors. Our configuration is the equivalent to a Lead-I ECG placement.

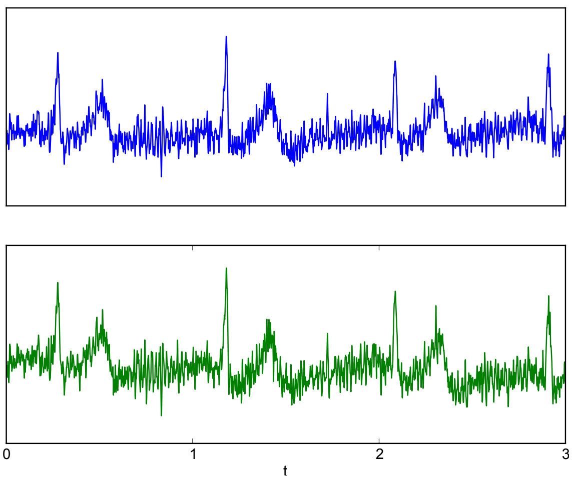

Figure 3: Example of collected data: At the top, in blue, the ECG signal acquired at the hand palm using dry Ag/AgCl electrodes; at the bottom, in green, the ECG signal acquired at the fingers using Electrolycras.

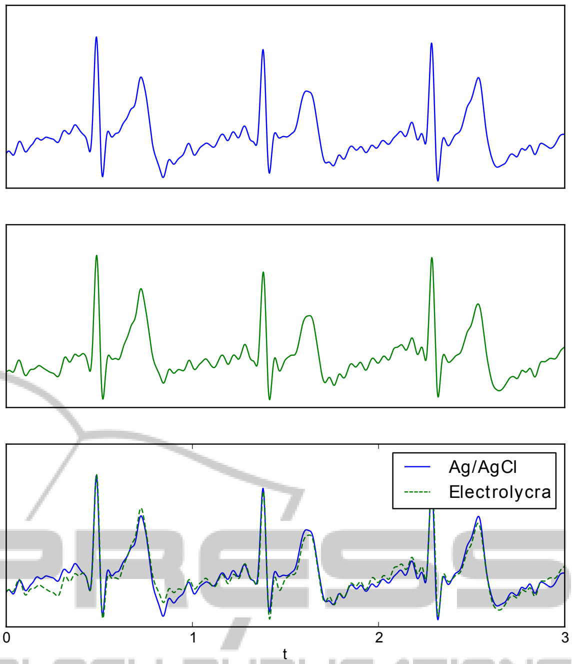

Figure 4: Example of filtered data: At the top, in blue, the ECG signal acquired at the hand palm using dry Ag/AgCl electrodes; at the middle, in green, the ECG signal acquired at the fingers using Electrolycras.

5 DISCUSSION

Previous work from our group has shown the potential of ECG signals collected at the hands and fingers for biometric applications. In (Lourenço et al., 2011b), a single lead setup with a standard ECG triode sensor was used to acquire signals at the hand and fingers level.

In a standard configuration, the signal conditioning circuitry measures an electrical potential difference between two points, referred to the common mode voltage of the body. The later is provided through a ground lead directly connected to the person. This setup is particularly advantageous since the electronics is simpler, however, three contact points are always required.

With our work, we were able to further improve this setup, by introducing a virtual ground, which generates a reference voltage to the signal conditioning circuitry from the sensor supply voltage. This configuration only requires 3 additional components in the circuit, and allows the ECG signal acquisition to be performed with only 2 contact points, by eliminating the ground lead.

In the work by (Lourenço et al., 2011a) and (Silva et al., 2011) tests were performed with this experimental setup, with the purpose of evaluating the biometric potential. Results have shown that the obtained signals enable recognition rates within the confidence intervals of what is known in the field.

6 CONCLUSIONS

The field of application of electrocardiographic signals is expanding to new areas, which far extend the medical and quality of life applications to which it is typically associated with. Biometrics is currently emerging as one of these novel application fields.

Within the scope of biometric recognition, conventional acquisition apparatuses have specificities which limit the acceptability by the potential end-users. This arises from the fact that, in general, devices require pre-gelled electrodes or conductive paste to acquire the signals, but more importantly, because they need to be applied to the subjects body.

Furthermore, current methods require three contact points with the subjects body, namely for positive (+) and negative (-) poles, plus a ground (GND) lead. In this paper we presented an experimental setup, which allows ECG acquisition in a format that has usability levels comparable to those found in readers of other biometric modalities (e.g. fingerprint, hand geometry, among others).

Our approach recurs to a custom two-lead ECG sensor, that can use either dry Ag/AgCl electrodes or Electrolycras as interface with the skin. For signal acquisition, the user only needs to rest his/her hand and fingers over the reader without any other constraint.

Experimental results have revealed that the collected signals provide adequate informative content. In particular, the QRS-T segments are detectable with high definition. Also, a good correlation was found between signals acquired with each type of electrode, material allowing the biometric system designer to select the type of material that improves the usability on the intended application.

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