34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Context Aware Sensing for Health Monitoring

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Abstract— **Health Monitoring systems with textile sensors offer more comfort compared to gel electrodes, however they tend to suffer from poor skin contact and motion artifacts. In order to improve the monitoring reliability, we propose to apply multiple sensors and context aware sensing. A context aware monitoring system can adapt monitoring according to changes in the environment and the behavior of people. In this paper, we propose a method with a Context Aware Selection Algorithm (CASA) to select the best signals obtained from multiple textile sensors, and thereby enhancing the reliability of electrocardio-gram (ECG) monitoring. In experiments with adult participants we found that CASA indeed enhances continuous monitoring by selecting the best quality ECG derivation which varies with the context, in this case the posture of the participant. CASA is suitable for embedding in the smart jacket, which is a comfortable monitoring system for babies admitted to the Neonatal Intensive Care Unit (NICU).**

I. INTRODUCTION

Users prefer health monitoring systems that are comfortable to wear, reliable and don't raise false alarms. A context aware system might be the solution to increase the reliability of comfortable sensors and provide only relevant information. Context awareness is defined as: "*the situation of a wearable or mobile computer being aware of the user's state and surroundings, and modifying its behavior based on this information*" [1]. Medical monitoring and treatments adapted to a subject's condition help not only enhance the clinical results, they also improve comfort and bonding of patient and people around by reducing the stress or pain.

The Eindhoven University of Technology (TU/e) in the Netherlands has started a 10-year project in cooperation with the Máxima Medical Center (MMC) in Veldhoven, the Netherlands. The collaboration between TU/e and MMC aims to bring together a multidisciplinary network of specialists in sensor technology, medical clinics and signal processing and develop revolutionary neonatal monitoring solutions. Several research results on non-invasive neonatal monitoring have been reported: textile electrodes for ECG [2], a power supply based on contactless energy transfer [3], blood oxygen saturation monitoring using reflectance pulse oximeter [4,5], temperature monitoring [6], cardiopulmonary resuscitation support [7], a design of wireless sensor system [8] and a textile mat to study the pressure distribution [9]. The smart jacket [2] (Fig.1) is designed as an unobtrusive wearable monitoring platform for these additions to improve comfort and support the bonding between family and infant.

Literature [10, 11] shows that although textile sensors offer more comfort, their robustness in providing an accurate ECG signal is lower. This is caused by occasionally poor skin-contact and sensitivity to motion resulting in artifacts. In [12] we reported our findings from an explorative clinical data collection of multi-dimensional data with premature babies in the NICU context. We looked for correlations in signal quality and context, in order to explore whether a context aware multi-sensor system can be the solution to improve the robustness. We concluded that a local indicator as input for a sensor selection algorithm, such as impedance or pressure would provide more accurate information about which sensor has better skin contact. We also found that the quality varies over time and between sensors under different circumstances, which means a sensor selection algorithm indeed has potential to increase the reliability. The accelerometer data correlated well with the presence of movement artifacts and changes in ECG signal quality, and therefore could be used to trigger the algorithm to perform the sensor selection and prevent false alarms.

Figure 1. Neonatal Smart Jacket [2]

The goal of this study is to design a sensor selection algorithm able to find the best quality ECG signal from multiple smart textile sensors, and test whether the system provides robust continuous monitoring. We propose a Context Aware Selection Algorithm (CASA). The system works as following: multi-channel ECG signals are obtained with the smart jacket's textile electrodes connected to an amplifier. The CASA algorithm selects the best signal for health monitoring in different situations. In the case of neonatal monitoring, the system is expected to provide robust monitoring when the babies are in various sleeping postures inside the incubator and during the Kangaroo Mother Care. We tested what the impact of the posture is on the signal quality in experiments with adults wearing an adult version of the jacket. We tested the performance of the CASA algorithm and assessed the quality of the selected ECG

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* The authors gratefully acknowledge the support of the Innovation-Oriented Research Programme 'Integral Product Creation and Realization (IOP IPCR)' of the Netherlands Ministry of Economic Affairs, Agriculture and Innovation.

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978-1-4577-1787-1/12/$26.00 ©2012 IEEE

signals by comparing them to ECG signals from the other derivations.

II. SYSTEM DESIGN

The system used for this research contains several components: data acquisition, amplification and software. This section introduces the smart jacket for ECG sensing, TMSI amplifier and the software for data acquisition.

A. *Smart jacket*

An adult jacket was created to facilitate the experiments on adults. The configuration of the adult jacket prototype can be seen in Fig.2. The multi-sensor recording is realized with two sets of textile electrodes: one set on the back (RA3, LA3 & LL3) and one set on the front (RA2, LA2 & LL2). Additionally, a textile electrode as a GND is located on the front (RL). As seen in Fig.2 the electrodes circled are used in the study. The electrodes are 3 cm x 3 cm square shaped and attached with only one side to the jacket, in order to prevent undesirable artifacts, due to the textile sensor being under strain when the jacket is being stretched.

Figure 2. Adult jacket. The circled electrodes are the used in this study.

B. *Amplifier*

TMSI Refa8-32 amplifier in combination with ASA-lab 4.7.3 software by ANT was used during the system testing and development [13]. In this study we used a sample frequency of 512 Hz, which is sufficient for ECG analysis. Unipolar channels are chosen for acquisition of the ECG because they provide flexibility in generating derivations. Table 1 shows the 15 possible derivations by the 6 channels.

Table 1. Derivations generated from the leads.

RA2-LA2	D1	**RA2-LL2**	D2	**RA2-RA3**	D3
RA2-LA3	D4	**RA2-LL3**	D5	**LA2-LL2**	D6
LA2-RA3	D7	**LA2-LA3**	D8	**LA2-LL3**	D9
LL2-RA3	D10	**LL2-LA3**	D11	**LL2-LL3**	D12
RA3-LA3	D13	**RA3-LL3**	D14	**LA3-LL3**	D15

III. ALGORITHM DEVELOPMENT: CASA

A. *Algorithm flow*

The block diagram of CASA is illustrated in Fig. 3. The algorithm starts by loading the raw ECG data from the ASCII file which was exported by the ASA software. Then the algorithm creates all the possible derivations as shown in Table 1. Next, the Power Spectrum Density (PSD) block transfers the data from time domain into the frequency domain based on Welch periodogram method, which splits data into overlapping segments, computes modified periodograms of the segments, and averages the resulting periodograms to produce the power spectral density estimate. The result of this block will be a matrix with the PSD of all the derivations.

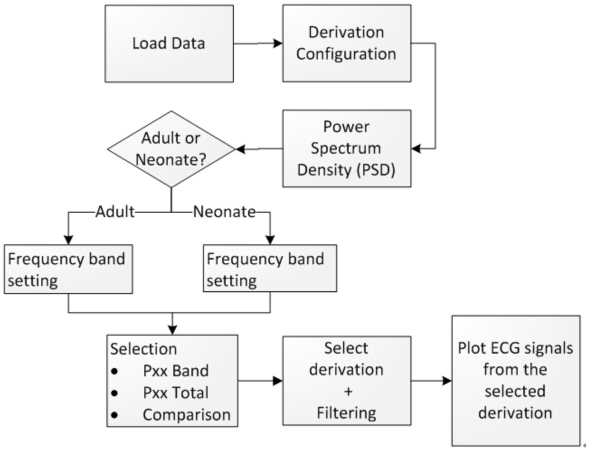


Figure 3. CASA Block Diagram

This algorithm is based on the idea that the ECG has relevant information only in specific bands of the power domain. It is important to be aware that the design is for neonates, however for testing purpose the settings had to be adapted for adults. Therefore, a distinction between adults and babies was included in the algorithm, in which different values for the band frequency can be used. As seen in [14], the adult ECG contains most of the diagnostic information below 100 Hz, although low amplitude, high-frequency components as high as 500 Hz have been detected and studied. The QRS of infants often contains important components as high as 250 Hz [15]. A frequency band between 1.3 Hz and 47 Hz is selected for the adults, which removes baseline noise and powerline interference. These values are based on evaluation of the adult PSD in the collected data and due to the fact that frequency values greater than 50 Hz provide a spectrum of 20 dB lower.

In the selection block, P_{xx_band} is a row vector with the summation of all the power from any derivation in the signal frequency bands. P_{xx_total}, is a row vector with the summation of all the components of the PSD from all derivations in the spectrum. These two values are compared by dividing P_{xx_band} by P_{xx_total} and a coefficient vector is obtained from $coefficient = P_{xx\_band} / P_{xx\_total}$. The coefficients represent for each derivation how powerful the signal is in the bands of interests against the total PSD. The derivation with the highest coefficient is expected to provide the best quality ECG signal compared to other derivations. In the final block, CASA plots the ECG trace. For the purpose of testing, the 'winner' of the selection is plotted and the worst other derivation is used for comparison.

IV. EXPERIMENTS AND RESULTS

A. Set-up

Experiments were carried out to study (1) the electrode-skin contact in the jacket and (2) the ECG signal quality after implementation of CASA, at the Biofeedback-lab in the department of Industrial Design at TU/e. Fig. 4 illustrates the setup.

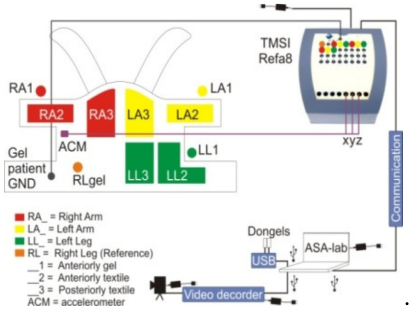


Figure 4. Setup of data collection.

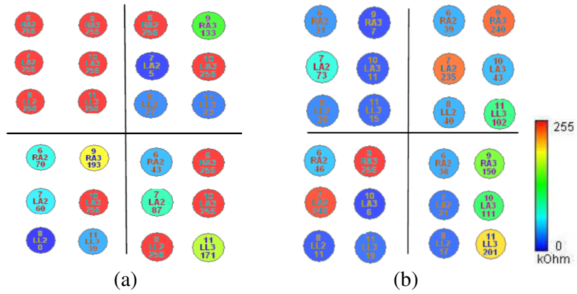
Four relevant situations (Fig. 5) were recreated with the participants wearing the adult jacket for ECG recordings. These relevant situations are the four postures in which a baby sleeps inside the incubator: supine, left-sided, right-sided and prone. Recordings for each position have durations of 1 to 2 minutes.

Figure 5. Four different postures

Measurements were carried out on two subjects. Subject A is thinner than subject B, thus the jacket fits tightly on subject B. The recordings with the two participants took place in serie shortly after each other, with equal system settings for both, to provide a consistant environment. The ECG measurements in four postures (Fig. 5), were fed into the CASA algorithm in order to select the ECG signal with the higher power density in the bands of interest of the spectrum. Additionally the impedance of each electrode in each posture was measured at the onset of the recordings, in order to evaluate the electrode skin contact for the four different postures of the patient.

We used the 'Check Impedance' tool of ASA software to measure the impedance values of all the textile electrodes. The software allowed to sample the impedance once before the recording, instead of throughout. The scale follows both a number and a color code. The values run from 0 KΩ, where the contact is optimal, to 256 KΩ in which the contact is poor or non-existent.

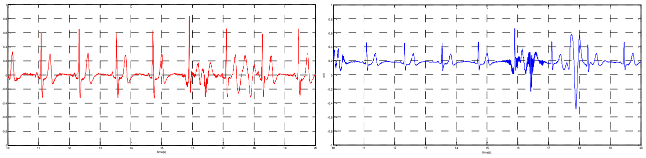
Fig. 6 shows the impedance measurements for subjects A and B under the four postures. For subject A, the worst impedance values showed while the subject laid in supine position and the best showed in the left-sided position, as seen in Fig.6 (a). From Fig. 6 (b), it can be seen that subject B that was heavier and fitted the jacket tightly had several channels with good skin contact in any posture. Most likely the fit and the weight played part in this, although the subjects skin contact proporties such as the level of sweat could have varied as well. Generally it was observed that application of pressure to the textile electrode resulted in lower impedance and better skin electrode contact. A higher coverage of electrodes in the jacket would enable to evaluate the correlation better. We conclude that likely the tight fit in combination with more weight on the electrode, resulted in overall better skin contact. This issue is further addressed in section V Discussion.



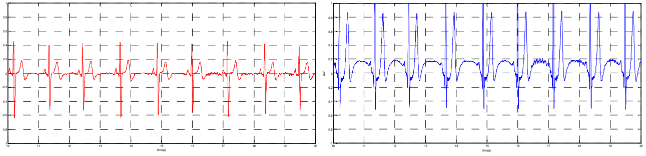
(a) (b)

Figure 6. (a) Impedance values of subject A. (b) Impedance values of subject B. Upper left: Supine position, upper right: Right-side position, lower left: Left-side position, lower right: Prone position.

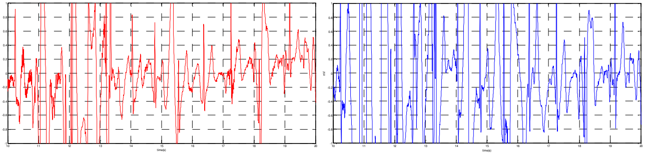
Fig. 7 and Fig. 8 show the ECG recordings of subject A and B respectively under the four positions. For each position, two ECG traces of 10s are presented. The left/red trace is the best ECG derivation selected by CASA and the right/blue trace is the worst derivation selected by CASA.



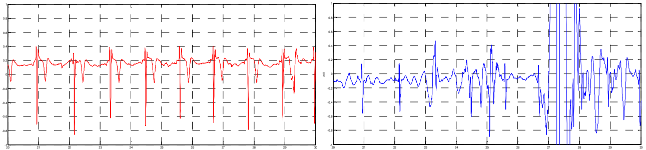
(a) LL2-LA3 (D11) LL2-LL3(D12)



(b) RA2-RA3 (D3) LA2-RA3 (D7)

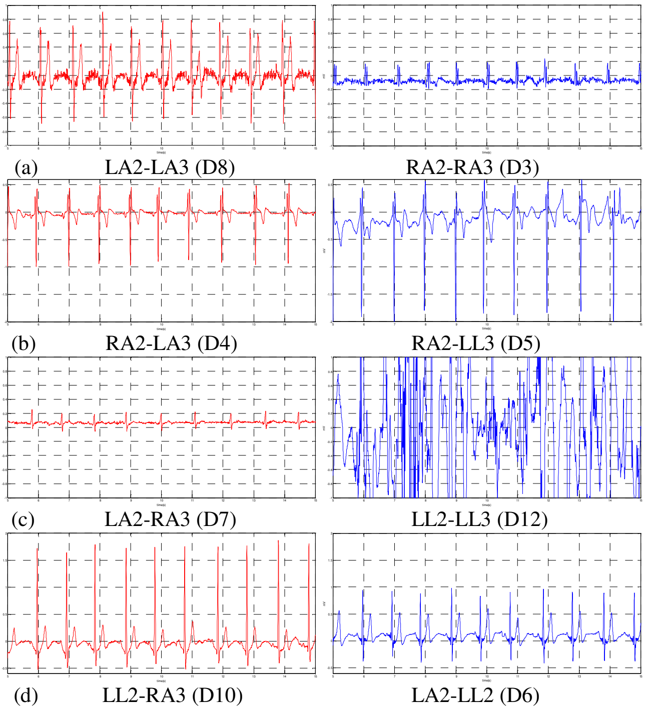


(c) LL2-RA3 (D10) LA2-RA3 (D7)



(d) RA2-LL3 (D5) RA2-RA3 (D3)

Figure 7. ECG recordings on subject A with application of CASA. (a) supine; (b) left-sided (c) right-sided (d) prone (In each subfigure, the left/red trace is a frame from the selected best derivation, and the right/blue trace is from the worst derivation. The derivations marked according to Table 1 are presented under each subfigure).


(a) LA2-LA3 (D8) RA2-RA3 (D3)

(b) RA2-LA3 (D4) RA2-LL3 (D5)

(c) LA2-RA3 (D7) LL2-LL3 (D12)

(d) LL2-RA3 (D10) LA2-LL2 (D6)

Figure 8. ECG recordings on subject B with application of CASA. (a) supine; (b) left-sided (c) right-sided (d) prone (In each subfigure, the left/red trace is frame from the selected best derivation, and the right/blue trace is from the worst derivation. The derivations marked according to Table 1 are presented under each subfigure).

The ECG diagrams show that the ECG signals from the best derivation are more stable and less noisy than those from the worst derivations. The signals measured on subject B generally have a better quality than the measurements on subject A, which confirms with the findings in the discussion of the previous paragraph about impedance and skin contact measured at the onset of the recoring. For subject B, even from the worst derivations, clear ECG R-peaks can be read. For both subjects, the ECG signals under the left sided position are with clear QRS complex (see Fig.7 (b) and Fig. 8 (b)). The signals from the best derivations under the prone position are better than the signals from the supine position, especially for subject B the best derivation provides the strongest signal as shown in Fig. 8 (d).

V. DISCUSSION

CASA achieves context aware sensing by selecting the high quality ECG signal under different postures. For suject A, ECG signals with clear QRS complex were obtained in all postures except for the right-sided position. For subject B, the selected derivations provide good quality ECG signals for all the positions.

Derivations for the best signals are different depending on the postures and the condition of the sensor interface for each subject. For both subjects, the signal quality for the right-sided position is lower compared to the signals of other positions. Since the quality of signal is more problematic in the sided positions, it would be interesting to explore whether adding more electrodes which cover both sides of the body helps to enhance the signal quality.

Attaching pressure sensors nearby the electrodes and recording impedance values for each sensor along the entire measurements will provide more insights on the system performance. Accelerometers will provide more information on the correlation of the physiological signals and the context.

Tightness of the jacket likely helps to improve the electrode-skin contact. In terms of comfort it can only be applied on adults during a short period of time, but since neonatal monitoring requires continuous monitoring on babies, a very tight jacket is not an option for the babies' normal growth and development. We have been working on a new design of the neonatal jacket for providing better electrode-skin contact. In summary, dedicated design addressing comfort, ergonomics and reliability together with smart algorithms like CASA are the key success factors for context aware sensing in health care.

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