Modelling and simulation of skin-stretch-caused motion artefacts in single-channel ECG signal

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1 Introduction

Motion artefacts are important and yet unsolved problem in mobile patient monitoring. Stretching of skin causes variations of its electrical properties and is known to be among the strongest sources of motion artefacts. Modelling can be helpful in better understanding of artefacts in ECG and in developing model-based techniques for cleaning or interpreting noisy ECG signals. This work combines existing experimental results from the field of skin physiology [1] with theoretical analysis of ECG amplifier [4]. Simulations enable to observe the complex process of generation of artefact waveforms. The simulator based on the artefact model can be used as experimental environment offering the unique possibility of capturing clean reference ECG besides noisy ECG.

2 Methods

The model was implemented as simulation in Matlab Simulink. The simulator driven by stretch forces generates a set of signals: ECG signal with movement artifacts, clean reference ECG, skin potential and impedance separately for each electrode.

2.1 General model structure

Artefact sources are modelled as electrical elements whose voltage and impedance vary in response to stretch. Variable voltages and impedances of both artefact sources together with ECG provide input for a recorder circuit. Figure 1 shows the model structure. It can be considered as an extension of a commonly agreed structure [3], in addition to which skin sites are modelled in detail and a recorder model is supplemented by amplifier input stage analysis [4] and a signal filtering stage.

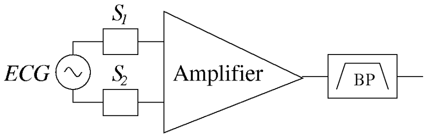


Figure 1: Recorder input stage, ECG source and artefact sources. S_1 - artefact source 1, S_2 - artefact source 2, BP - band-pass filter

2.2 Electrical model of skin under electrode

The skin site is modelled as a three-component circuit presented in [1]. The resistance R_c of stratum corneum is considered constant, while R_t and I_t referring to transitional cells are variable in response to stretch forces. Changes in stretch force determine changes of R_t and I_t and result in voltage and resistance change of a modelled skin fragment. Variation of voltage and resistance conform with step responses presented in [1]. Capacitancies are neglected, as the signals of interest have relatively low frequencies [2]

2.3 Recorder model

The amplifier (Figure 2) delivers voltage U_{out} which can be expressed as:

$$U_{out} = \frac{R_I}{R_I+R_1+R_2}[U_1-U_2+ECG-I_B(R_1+R_2)]$$

In addition to the analysis in [4] the model takes into account both artefact sources separately which

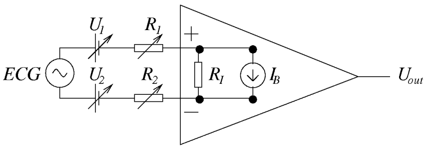
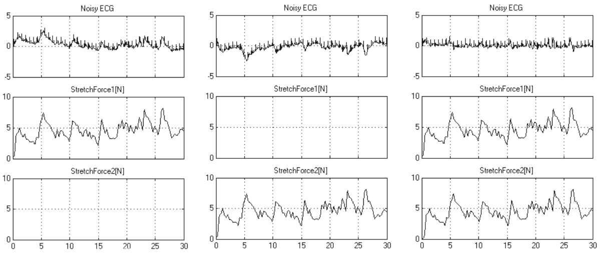


Figure 2: Recorder input stage. ECG - variable ECG voltage, U_1 - voltage across electrode1/skin1, U_2 - voltage across electrode2/skin2, R_1 - resistance across electrode1/skin1, R_2 - resistance across electrode2/skin2, R_I - input impedance, I_B - bias (leakage) current, U_{out} - output voltage



a) b) c)

Figure 3: Experiment results: a) only S_1 stimulated, b) only S_2 stimulated, c) both S_1 and S_2 stimulated. Stimulus for S_2 delayed by 200ms

enables to model complex interaction of all electrical components. A closer look at the equation reveals that the output voltage U_{out} is not a simple sum of voltages U_1, $-U_2$ and ECG, but is influenced by varying resistances R_1 and R_2. The last voltage component, $-I_B(R_1 + R_2)$ is proportional to the leakage current I_B. Additionally, the voltage is scaled according to factor $\frac{R_I}{R_I+R_1+R_2}$.

3 Results

The shape of artefacts depends on the distribution of stretch forces over the considered skin fragments. Skin-stretch under only one electrode causes prominent artefacts. Stretch under electrode1 results in positive deflections (Figure 3.a) while skin under electrode2 is responsible for negative deflections of ECG signal (Figure 3.b).

Figure 3.c shows an example where the stimulus for electrode2 is delayed by 200ms. This results in artefacts of smaller amplitude but still sharp edges. The exact stimulus for both artefact sources produces almost no artefact, as oppositely oriented voltages cancel.

4 Discussion

Simulation results show strong influence of movement distribution over electrodes on the observed waveform of artefact. It implies the importance of monitoring of states of both electrodes for the task of designing model-based artefact suppression algorithms. Skin-stretch model is based on measurements taken with gel electrodes only [1], and does not account for any nonstationary or stochastic effects. However, qualitative features of synthesized artefacts conform well with motion artefacts in real recordings, although the appearance of sythesized signals is more smooth. As far as available physiological data permit, the model can be easily extended to include other mechanical effects which might affect voltages and impedances of sources S_1 and S_2.

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References

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