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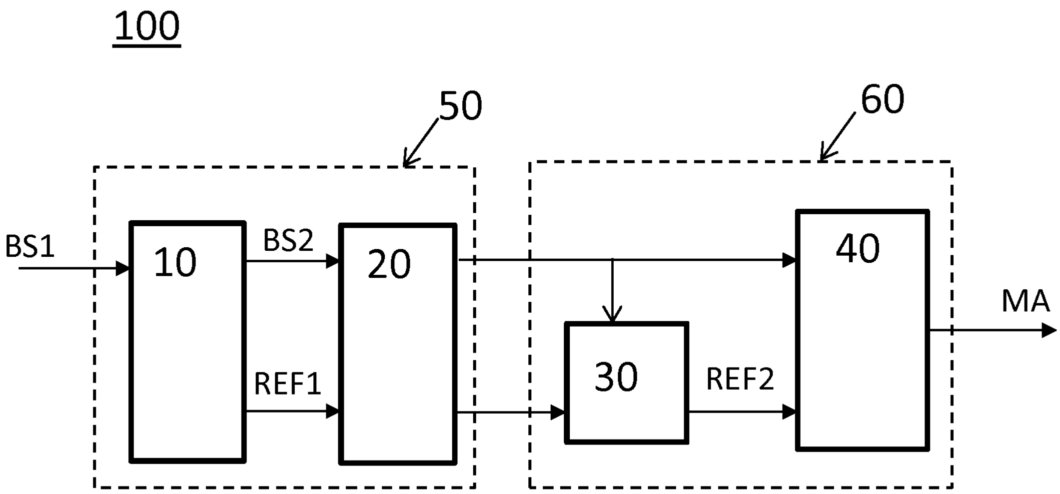
(54) **System and a method for acquisition of biopotential signals with motion artifact reduction.**

(57) The invention relates to a biopotential signal acquisition system (100) comprising: an analogue readout unit (10) configured to receive an analogue biopotential signal (BS1), which may be acquired from at least one electrode attached to a body; and to extract an analogue measured biopotential signal (BS2) and an analogue reference signal (REF1); an ADC unit (20) configured to provide a digital version of the analogue measured biopotential signal (BS2) and the analogue reference signal (REF1); a digital filter unit (40) configured to calculate a digital motion artifact estimate (MA) based on the digital version of the measured biopotential signal (BS2) and the reference signal (REF1). The system further comprises a reference signal processing unit (30) configured to convert the reference signal (REF1) into a new reference signal (REF2) being provided to the digital filter unit (40) based on the correlation between the measured biopotential signal (BS2) and the reference signal (REF1). The invention also relates to an electronic device and a method for acquisition of biopotential signals.

Figure 1



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Description

Technical Field

[0001] The present invention relates generally to the field of biopotential signal acquisition systems and more specifically to a system and a method for acquisition of biopotential signals with motion artifact reduction using digital adaptive filtering.

Background

[0002] Ambulatory monitoring of biopotential signals, such as electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), etc., is a highly relevant topic in personal healthcare. A key technical challenge in such application environments is overcoming motion artifacts that significantly affect the recorded biopotential signals. An approach to reduce motion artifacts is by using digital adaptive filtering. For example, a known biomedical acquisition system with motion artifact reduction is disclosed in EP 2 591 720 A1, which uses digital adaptive filtering (e.g. a LMS filter), implemented in a digital domain, to calculate a motion artifact estimate which is then fed back to the analogue domain and subtracted from the measured ECG before final amplification. Another known technique for motion artifact removal using a two-stage cascade LMS adptive filter is disclosed in the document "Motion Artifact Removal using Cascade Adaptive Filtering for Ambulatory ECG Monitoring System", by Hyejung Kim et al., Biomedical Circuits and Systems Conference (BioCAS), November 2012 IEEE, Hsinchu, Taiwan.

Summary

[0003] According to one aspect of the present invention, a new biopotential signal acquisition system is provided with improved motion artifact reduction. According to another aspects the invention is advantageous for ambulatory and/or low power biopotential monitoring applications.

[0004] According to an exemplary embodiment, there is provided a biopotential signal acquisition system comprising: an analogue readout unit configured to receive an analogue biopotential signal and to extract, from that received analogue biopotential signal, an analogue measured biopotential signal and an analogue reference signal; an ADC unit configured to provide a digital version of the analogue measured biopotential signal and the analogue reference signal; a digital filter unit configured to calculate a digital motion artifact estimate based on the digital version of the measured biopotential signal and the reference signal; and wherein the system further comprises a reference signal processing unit configured to convert the reference signal into a new reference signal being provided to the digital filter unit based on the correlation between the measured biopotential signal and the reference signal. The received analogue biopotential signal may be acquired, for example, from at least one electrode attached to a living being's body.

[0005] According to an exemplary embodiment, the correlation between the measured biopotential signal and the reference signal may be estimated by calculating the correlation between the motion artifact estimate signal and the reference signal.

[0006] According to an exemplary embodiment, the correlation between the measured biopotential signal and the reference signal may be estimated by calculating the correlation between the analogue biopotential signal and the reference signal.

[0007] According to an exemplary embodiment, the polarity of the new reference signal may be calculated based on the correlation between the measured biopotential signal and the reference signal. The polarity of the new reference signal may be the same or opposite to the polarity of the reference signal depending on the correlation between the measured biopotential signal and the reference signal.

[0008] According to an exemplary embodiment, the reference signal processing unit may be implemented in an analogue domain part or digital domain part of the system.

[0009] According to an exemplary embodiment, the digital filter unit may implement or runs a digital adaptive filter, such as, for example an LMS filter.

[0010] According to an exemplary embodiment, the reference signal may be an electrode-tissue impedance signal. According to an exemplary embodiment, the analogue biopotential signal may be an ECG signal.

[0011] There is also provided and electronic device comprising a biopotential signal acquisition system according to any of the embodiments herein described.

[0012] There is also provided a method for acquisition of biopotential signals, comprising: extracting, from an analogue biopotential signal, an analogue measured biopotential signal and an analogue reference signal; converting the reference signal into a new reference signal based on the correlation between the measured biopotential signal and the reference signal; and calculating a digital motion artifact estimate based on the digital version of the measured biopotential signal and the new reference signal.

[0013] Certain objects and advantages of various new and inventive aspects have been described above. It is to be understood that not necessarily all such objects or advantages may be achieved in accordance with any particular embodiment of the present invention. Those skilled in the art will recognize that the solution of the present invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages without necessarily achieving other objects or advantages.

Brief description of the drawings

[0014] The above and other aspects of the system and method for acquisition of biopotential signals according to the present invention will be shown and explained with reference to the non-restrictive example embodiments described hereinafter.

Figure 1 shows a first exemplary block diagram of a biopotential signal acquisition system according to an embodiment of the invention.

Figure 2 shows a second exemplary block diagram of a biopotential signal acquisition system according to an embodiment of the invention.

Figure 3 shows a flow diagram of a method for acquisition of biopotential signals according to an embodiment of the invention.

Figure 4 illustrates exemplary graphs of signals generated in a biopotential signal acquisition system according to an embodiment of the invention.

Detailed description

[0015] In the following, in the description of exemplary embodiments, various features may be grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This is however not to be interpreted as the invention requiring more features than the ones expressly recited in the main claim. Furthermore, combinations of features of different embodiments are meant to be within the scope of the invention, as would be clearly understood by those skilled in the art. Additionally, in other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure the conciseness of the description.

[0016] **Figure** 1 shows a first exemplary block diagram of a biopotential signal acquisition system 100 according to an embodiment of the invention. The system comprises an analogue domain part 50 configured to receive at least one analogue biopotential signal BS1, which may be acquired, for example, from at least one sensor electrode attached to a living being body, and comprises an analogue readout unit 10 which extracts at least one analogue measured biopotential signal BS2 and at least one analogue reference signal REF1. The analogue measured biopotential signal BS2 and the analogue reference signal REF1 are then provided to an analogue-to-digital converter (ADC) unit 20, which comprises one or more ADCs configured to convert those signals into digital versions which are then handled in the digital domain part 60 of the system. A reference signal processing unit 30 receives the digital versions of the measured biopotential signal BS2 and the reference signal REF1 and is configured to calculate a correlation between both signals and generate a new reference signal REF2 based on the value of that correlation. Then, a digital filter unit 40 receives the measured biopotential signal BS2 and the new reference signal REF2 and calculates an estimated noise or motion artifact estimate MA, which is used to reduce the motion artifact from the measured biopotential signal.

[0017] According to an exemplary embodiment, the reference signal processing unit 30, based on the correlation value between the measured biopotential signal BS2 and the reference signal REF1, checks the polarity between both signals and adapts the reference signal REF1 based on such polarity value. If the polarity information has a first value, indicating that the reference signal REF1 has the same polarity as the measured biopotential signal BS2, then the reference signal processing unit 30 provides a signal REF2 that is the same as reference signal REF1 to the digital filter unit 40; if the polarity information has a second value, indicating that the reference signal REF1 has an opposite polarity than the measured biopotential signal BS2, then the reference signal processing unit 30 provides a signal REF2 that has polarity opposite to the polarity of the reference signal REF1.

[0018] According to an exemplary embodiment, the correlation value between the measured biopotential signal BS2 and the reference signal REF1 is calculated continuously. According to an exemplary embodiment, the correlation value varies between a maximum value, e.g. +1, in the case of a perfect positive (increasing) linear relationship (correlation) and a minimum value, e.g. -1, in case of a perfect decreasing (negative) linear relationship (anti-correlation), depending on the degree of linear dependence between the signals. The polarity calculation is then performed by comparing the calculated correlation value with a certain threshold value, which can be a certain predefined value or dynamically calculated. According to an exemplary embodiment, in case the calculated correlation value is equal to and/or greater than a certain threshold value, the polarity value is given a first value, e.g. 0, and in case the calculated correlation value is equal to and/or lower than a certain threshold value, the polarity value is given a second value, e.g. 1. According to an exemplary embodiment, once the polarity value is updated, it is maintained for a certain period of time in order to avoid oscillation.

[0019] According to an exemplary embodiment, the reference signal processing unit 30 generates a new reference signal REF2, which is an adaptation of the received reference signal REF1. By using the polarity information, the new reference input REF2 for the digital filter unit 40 is generated. The new reference signal REF2 is the same as the received reference signal REF1 in case the received reference signal REF1 has the same polarity as the measured biopotential signal BS2, and the new reference signal REF2 is a signal that has polarity opposite to the polarity of the reference signal REF1 in case the received reference signal REF1 has an opposite polarity than the measured biopotential signal BS2.

[0020] According to an exemplary embodiment, the correlation value between the measured biopotential signal BS2 and the reference signal REF1 may be also estimated by calculating the correlation between the estimated noise signal or motion artifact estimate MA at the output of the digital filter unit 40 and the reference signal REF1. According to another exemplary embodiment, the correlation value between the measured biopotential signal BS2 and the reference signal REF1 may be estimated by calculating the correlation between the analogue biopotential signal BS1 and the reference signal REF1.

[0021] Advantageously, according to an exemplary embodiment of the invention, the new reference signal REF2 has higher correlation with the measured biopotential signal BS2, which improves the performance of the digital filter unit 40 for calculation of the motion artifact estimate MA. In consequence, the motion artifact estimate MA can be calculated faster and with more accuracy, which in turn improves motion artifact reduction.

[0022] According to an exemplary embodiment, the biopotential signal acquisition system 100 works in real-time.

[0023] According to an exemplary embodiment, the analogue biopotential signal BS1 is an electrocardiogram signal and the reference signal REF1 is an electrode-tissue impedance signal. Other reference signals could be used, such as for example, a galvanic skin response (GSR), a photoplethysmogram (PPG) or a bio impedance signal.

[0024] According to an exemplary embodiment, the digital filter unit 40 may implement or run a digital adaptive filter, for example, a Least Mean Square (LMS) filter. According to an exemplary embodiment, the reference signal processing unit 30 may be implemented as part of the digital filter unit 40, for example, as part of the LMS filter. The digital filter unit 40 and the reference signal processing unit 30 may be implemented in hardware and/or software, in a dedicated digital domain part 60 and in the same chip as the analogue part 50. According to an exemplary embodiment, the digital filter unit 40 and the reference signal processing unit 30 may be implemented in hardware and/or software in an off-chip or external microcontroller or microprocessor.

[0025] According to one exemplary embodiment, all the modules sown in Figure 1 may be integrated on a single chip. This is advantageous for example to reduce the group delay for real time solution and/or to reduce the power consumption.

[0026] Figure 2 shows a second exemplary block diagram of a biopotential signal acquisition system 100 according to an embodiment of the invention. Basically the same working principle as the one explained Figure 1 applies, but for the fact that now the reference signal processing unit 30 is implemented in the analogue domain part 50 and adapts the reference signal REF1 in such domain.

[0027] Figure 3 shows a simplified flow diagram of a method for acquisition of biopotential signals with motion artifact reduction according to an embodiment of the invention. The method comprises, in a first step **S1,** calculating the correlation between a measured biopotential signal BS2 and a reference signal **REF1;** in a second step S2, calculating the polarity between the measured biopotential signal BS2 and a reference signal **REF1;** and, in a third step S3, generating a new reference signal REF2 which is provided to a digital filter unit for motion artifact estimation.

[0028] According to an exemplary embodiment, the correlation value between a measured biopotential signal BS2 and a reference signal REF1 is calculated in a first step **S1.** This may be done, in exemplary implementations, continuously and with a certain sampling rate in order to reduce the active power consumption. According to exemplary implementations, the estimated motion artifact signal MA may be also used for calculating the correlation value according to the equation:

$$corr_j = \frac{(dataIn\_A_j - \overline{dataIn\_A_{j-31:j}}) \cdot (dataIn\_B_j - \overline{dataIn\_B_{j-31:j}})}{32}$$

[0029] wherein *DataIn_A* is the motion artifact estimate signal MA, *DataIn_B* is the reference signal REF 1 and *corr* is the correlation value. The sampling rate (32) may be changed and is a design option.

[0030] According to an exemplary embodiment, the correlation value may be +1 in case of a perfect positive (increasing) linear relationship (correlation), and -1 in case of a perfect decreasing (negative) linear relationship (anti-correlation), and some value between -1 and 1 in all other cases, indicating the degree of linear dependence between the variables. As it approaches zero there is less of a relationship (closer to uncorrelated).

[0031] According to an exemplary embodiment, after calculating the correlation value, a polarity calculation may be performed, for example as a polarity change request signal, *req_p,* which is generated as the following equation:

$$req\_p_j = \begin{cases} 0, & \sum corr \geq CORR\_TH \\ 1, & \sum corr < CORR\_TH \end{cases}$$

[0032] Where *corr* is the correlation value and *CORR_TH* is a certain threshold value. To avoid the oscillation, once the polarity is updated, it may stay for a certain period of time, for example at least for 1 second. This period of time can be programmed and is a design option.

[0033] According to an exemplary embodiment, by using polarity information, the new reference input REF2 for the digital filter is updated as in the following equation:

$$ref_{neg} = REF\_OFF \times 2 - ref_{pos}$$

$$ref_{new} = \begin{cases} ref_{pos}, & polarity = 0 \\ ref_{neg}, & polarity = 1 \end{cases}$$

[0034] where *refpos* is the reference input, and *refneg* is the reference signal with opposite polarity. *REF_OFF* is a reference offset, which may be designed according to the acquisition environment such as subject, type of electrode, quality of electrode, etc., and its value may be adjusted at the beginning, and updated regularly during the operation.

[0035] Figure 4 illustrates exemplary graphs of the measured biopotential signal BS2, the reference signal REF1 and the new reference signal REF2 generated in a biopotential signal acquisition system according to an embodiment of the invention. As illustrated in the figure, the new reference signal REF2 is an adaptation of the reference signal REF1, in which the polarity of the reference signal REF1 changed such that it has a higher correlation with the measured biopotential signal BS2.

Claims

1. A biopotential signal acquisition system (100) comprising:

   an analogue readout unit (10) configured to receive an analogue biopotential signal (BS1) and to extract, from that received analogue biopotential signal, an analogue measured biopotential signal (BS2) and an analogue reference signal (REF1);
   an ADC unit (20) configured to provide a digital version of the analogue measured biopotential signal (BS2) and the analogue reference signal (REF1);
   a digital filter unit (40) configured to calculate a digital motion artifact estimate (MA) based on the digital version of the measured biopotential signal (BS2) and the reference signal (REF1);
   characterized in that
   the system further comprises a reference signal processing unit (30) configured to convert the reference signal (REF1) into a new reference signal (REF2) being provided to the digital filter unit (40) based on the correlation between the measured biopotential signal (BS2) and the reference signal (REF1).

2. A biopotential signal acquisition system according to claim 1, wherein the correlation between the measured biopotential signal (BS2) and the reference signal (REF1) is estimated by calculating the correlation between the motion artifact estimate signal (MA) and the reference signal (REF1).

3. A biopotential signal acquisition system according to claim 1 or 2, wherein the polarity of the new reference signal (REF2) is calculated based on the correlation between the measured biopotential signal (BS2) and the reference signal (REF1).

4. A biopotential signal acquisition system according to claim 3, wherein the polarity of the new reference signal (REF2) is the same or opposite to the polarity of the reference signal (REF1) depending on the correlation between the measured biopotential signal (BS2) and the reference signal (REF1).

5. A biopotential signal acquisition system according to any of the previous claims, wherein the reference signal processing unit (30) is implemented in an analogue domain part (50) or a digital domain part (60) of the system (100).

6. A biopotential signal acquisition system according to any of the previous claims, wherein the digital filter unit (40) implements or runs a digital adaptive filter.

7. A biopotential signal acquisition system according to claim 6, wherein the digital adaptive filter is an LMS filter.

8. A biopotential signal acquisition system according to any of the previous claims, wherein the reference signal (REF1) is an electrode-tissue impedance signal.

9. A biopotential signal acquisition system according to any of the previous claims, wherein the analogue biopotential signal (BS1) is an ECG signal.

10. Electronic device comprising a biopotential signal acquisition system (100) according to any of claims 1 to 9.

11. A method for acquisition of biopotential signals, comprising:

extracting, from an analogue biopotential signal (BS1), an analogue measured biopotential signal (BS2) and an analogue reference signal (REF1);
converting the reference signal (REF1) into a new reference signal (REF2) based on the correlation between the measured biopotential signal (BS2) and the reference signal (REF1); and
calculating a digital motion artifact estimate (MA) based on the digital version of the measured biopotential signal (BS2) and the new reference signal (REF2).

Figure 1

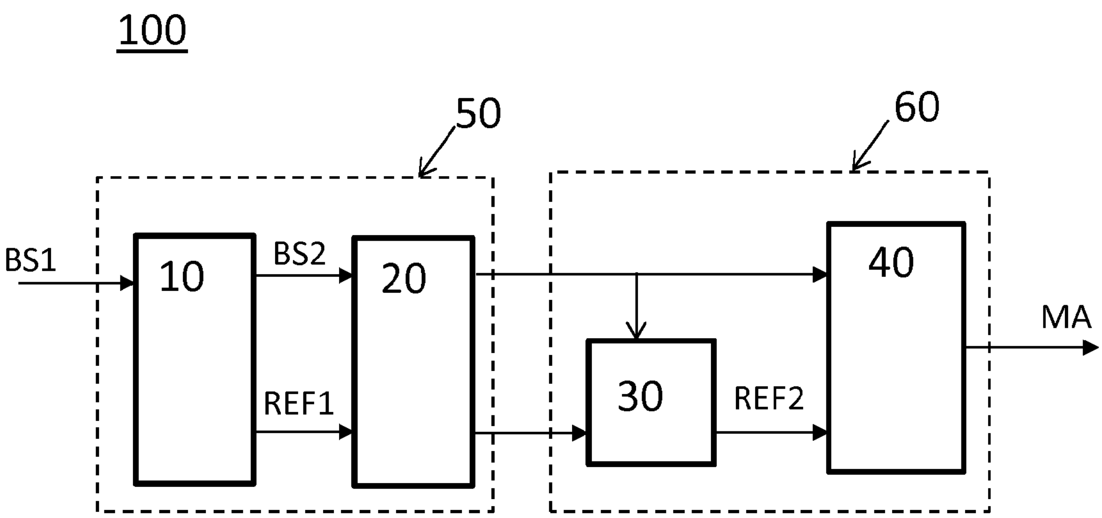


Figure 2

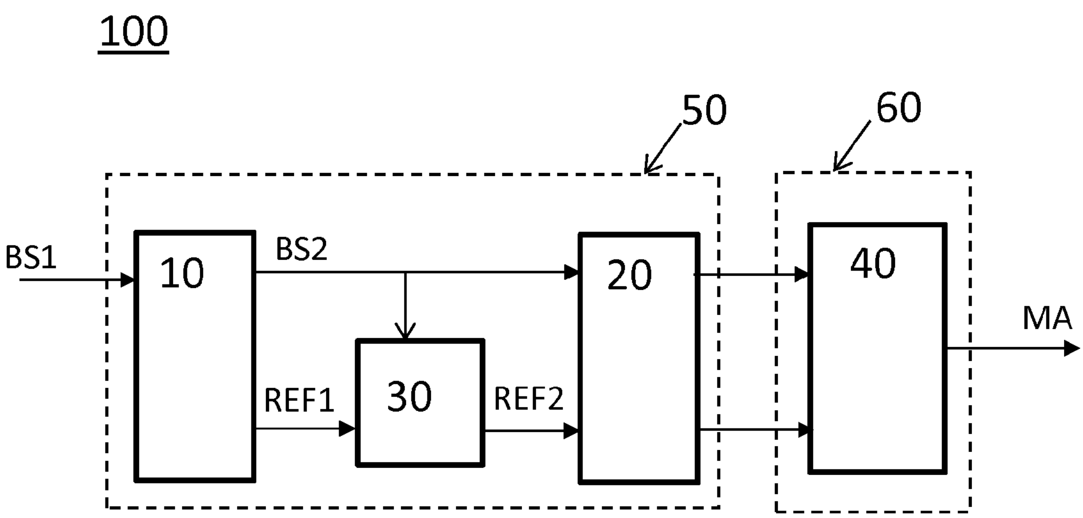


Figure 3

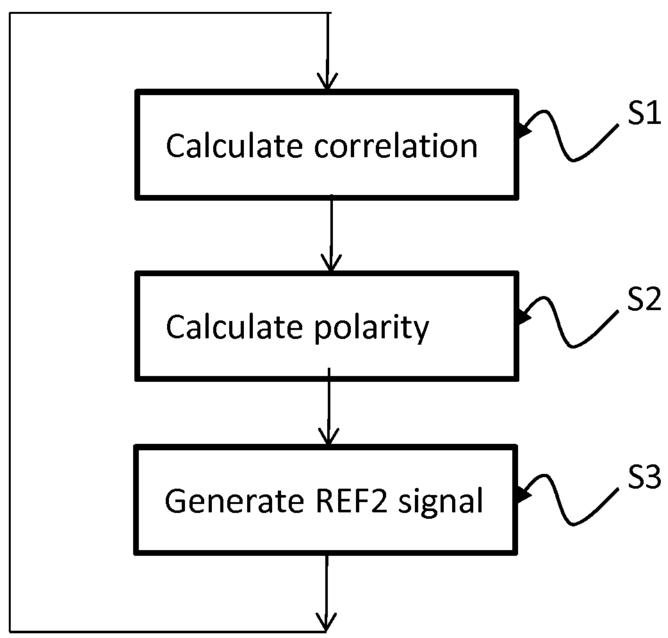
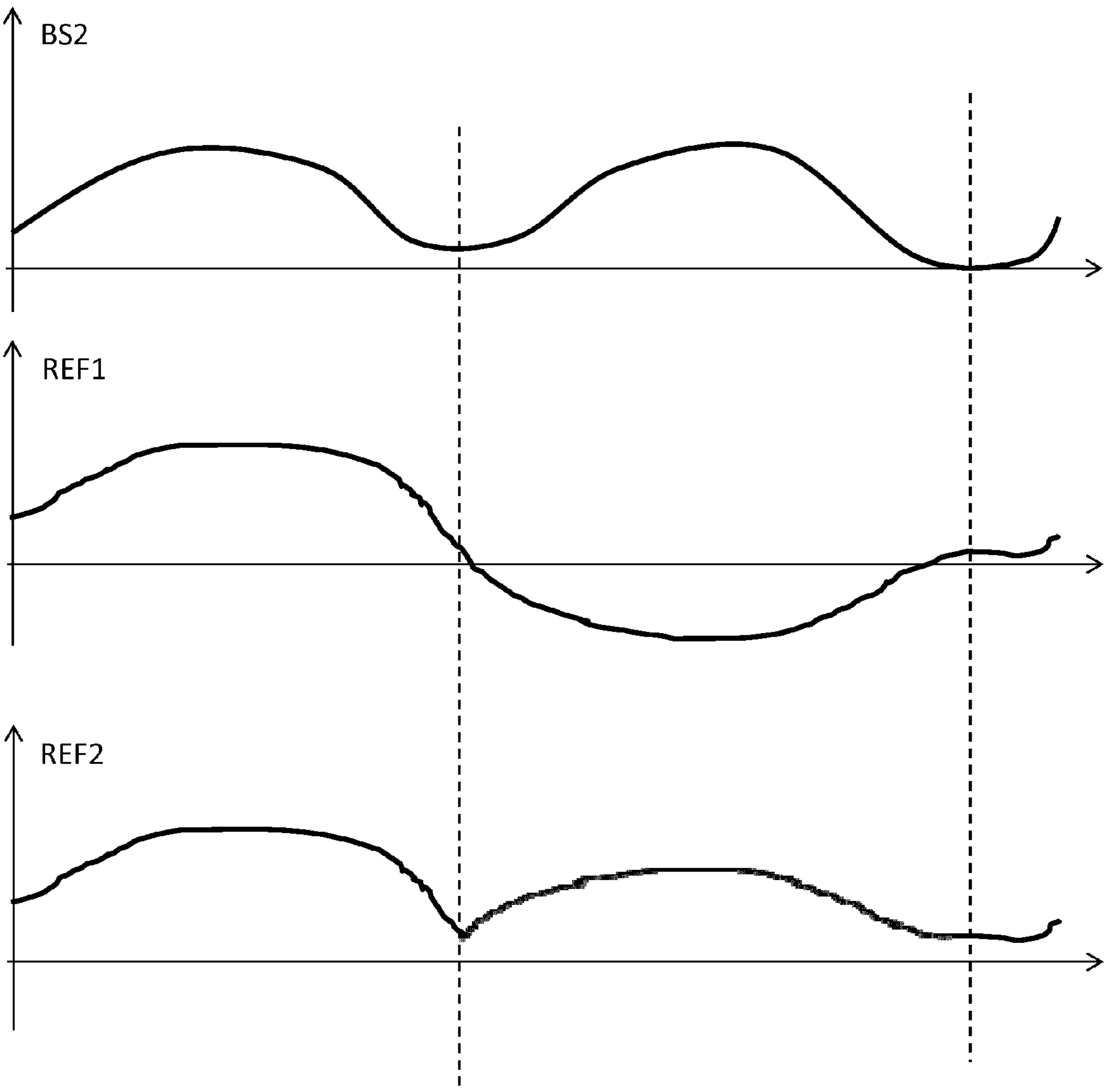

Calculate correlation
S1
Calculate polarity
S2
Generate REF2 signal
S3

Figure 4



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EUROPEAN SEARCH REPORT

Application Number
EP 14 15 6018

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	BUXI D ET AL: "Correlation Between Electrode-Tissue Impedance and Motion Artifact in Biopotential Recordings", IEEE SENSORS JOURNAL, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 12, no. 12, 1 December 2012 (2012-12-01), pages 3373-3383, XP011480243, ISSN: 1530-437X, DOI: 10.1109/JSEN.2012.2221163 * abstract * * I Introduction p. 3373-3374 * -----	1-11	INV. A61B5/00 A61B5/0428
A	SUNYOUNG KIM ET AL: "Real time digitally assisted analog motion artifact reduction in ambulatory ECG monitoring system", THE EFFECT OF APPLIED COMPRESSIVE LOADING ON TISSUE-ENGINEERED CARTILAGE CONSTRUCTS CULTURED WITH TGF-BETA3, IEEE, 28 August 2012 (2012-08-28), pages 2096-2099, XP032463352, ISSN: 1557-170X, DOI: 10.1109/EMBC.2012.6346373 * IIB System analysis p. 2097 * -----	1-11	TECHNICAL FIELDS SEARCHED (IPC) A61B
A	EP 2 561 805 A1 (SAMSUNG ELECTRONICS CO LTD [KR]) 27 February 2013 (2013-02-27) * paragraphs [0041] - [0054], [0104] - [0105] * -----	1-11	
A	US 2008/033266 A1 (DIAB MOHAMED K [US] ET AL) 7 February 2008 (2008-02-07) * paragraphs [0028], [0081] - [0091] * -----	1-11	

1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Berlin	2 April 2014	Trachterna, Morten

CATEGORY OF CITED DOCUMENTS

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& : member of the same patent family, corresponding document

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02-04-2014

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **HYEJUNG KIM et al.** Motion Artifact Removal using Cascade Adaptive Filtering for Ambulatory ECG Monitoring System. *Biomedical Circuits and Systems Conference (BioCAS,* November 2012 **[0002]**

专利名称(译)	用于获取具有运动伪影减少的生物电势信号的系统和方法。		
公开(公告)号	EP2886044A1	公开(公告)日	2015-06-24
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申请(专利权)人(译)	IMEC		
当前申请(专利权)人(译)	IMEC		
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其他公开文献	EP2886044B1		
外部链接	Espacenet		

摘要(译)

本发明涉及一种生物电势信号采集系统（100），包括：模拟读出单元（10），被配置为接收模拟生物电势信号（BS1），其可以从连接到身体的至少一个电极获取;并提取模拟测量的生物电位信号（BS2）和模拟参考信号（REF1）; ADC单元（20），被配置为提供模拟测量的生物电势信号（BS2）和模拟参考信号（REF1）的数字版本;数字滤波器单元（40），被配置为基于所测量的生物电势信号（BS2）和参考信号（REF1）的数字版本来计算数字运动伪影估计（MA）。该系统还包括参考信号处理单元（30），其被配置为基于测量的生物电势信号（BS2）之间的相关性将参考信号（REF1）转换为提供给数字滤波器单元（40）的新参考信号（REF2）。 ）和参考信号（REF1）。本发明还涉及用于获取生物电势信号的电子设备和方法。

Figure 1