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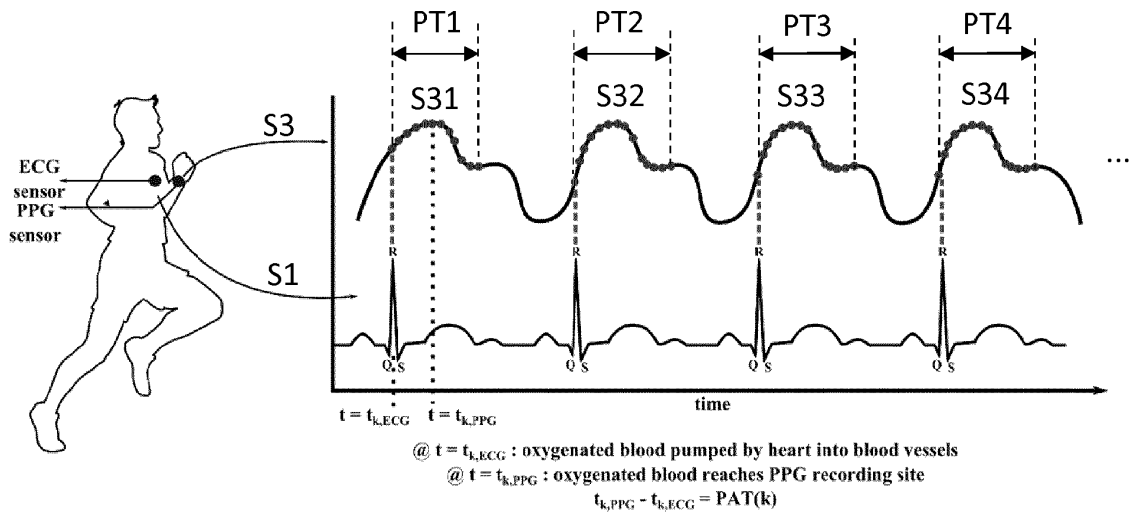
(54) SYSTEM AND METHOD FOR CUFFLESS BLOOD PRESSURE ESTIMATION

(57) An electronic system (100) for estimating a subject's arterial blood pressure, comprising: a heartbeat detection module (10) configured for receiving an electrocardiogram signal (S1) and detecting a QRS complex of said electrocardiogram signal; a PPG sensor module (20) configured for triggering a light emitter and thereby generating a plurality of samples of a PPG signal (S3); a blood pressure calculation module (30) configured for receiving information about the detected QRS complexes (S2) and the PPG signal samples (S3) and calculate at least one blood pressure value (SBP, DBP) based on a pulse arrival time period (PAT) between the electrocardiogram and the PPG signal; wherein the PPG sensor module (20) is further configured for receiving information about the detected QRS complexes (S2), for triggering, each time a QRS complex is detected, the generation of a plurality of samples of a PPG signal (S31 to S34) and for determining a PPG signal acquisition period (PT1 to PT4).

Figure 2



EP 3 381 356 A1

Description

Technical Field

[0001] The present description relates generally to electronic systems for arterial blood pressure estimation and more specifically to an electronic system, device and method for non-invasive cuffless blood pressure estimation.

Background

[0002] Continuous and non-invasive estimation of arterial blood pressure (BP) without using a cuff has gained emerging interest for health care applications. Instead of commonly used cuff-based measurements, changes in the Pulse Wave Velocity (PWV), i.e., the speed of a pressure pulse propagating along the arterial wall, can be an alternative approach for a continuous, non-invasive and indirect BP measurement. As a surrogate of PWV, an indirect estimation of BP can be also obtained with the use of Pulse Transit Time (PTT) or Pulse Arrival Time (PAT), as for example described in "Wearable Cuff-less PTT-based System for Overnight Blood Pressure Monitoring", by Yali Zheng et al., Engineering in Medicine and Biology Society (EMBS), 35th Annual International Conference of the IEEE EMBS, pp.6103-6106, Osaka 3-7 July 2013, in "A low-power, dual-wavelength photoplethysmogram (PPG) SoC with static and time-varying interferer removal" by E. S. Winokur et al., IEEE Transactions on Biomedical Circuits and Systems, vol. 9, no. 4, pp. 581 - 589, 2015, in "Cuff-less and noninvasive measurements of arterial blood pressure by pulse transit time" by C. Poon et al., 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, 2005, and in "An ultra low power pulse oximeter sensor based on compressed sensing" by P. K. Baheti et al., 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks, Jun 2009.

[0003] There is a motivation to improve current state of the art electronic systems and methods for non-invasive cuffless blood pressure estimation.

Summary

[0004] A new and improved system and method for non-invasive, cuffless blood pressure estimation is herein proposed, which allows to calculate the systolic and/or diastolic arterial blood pressure of a living being subject. According to an exemplary embodiment, the electronic system is advantageously able to calculate blood pressure values with a low power consumption. According to an exemplary embodiment, the electronic system advantageously reduces power consumption by reducing the number of photoplethysmogram (PPG) signal samples needed for calculating a pulse arrival time period (PAT) between an electrocardiogram (ECG) signal and a PPG signal. According to an exemplary embodiment, the electronic system advantageously reduces power consumption by reducing the number of times a light emitter in a PPG sensor module is triggered in order to generate PPG signal samples. According to an exemplary embodiment, the electronic system advantageously reduces power consumption by determining an optimal PPG signal sample acquisition period. According to an exemplary embodiment, the electronic system can be advantageously completely implemented in a wearable device with small form factor. According to an exemplary embodiment, the electronic system neither requires a base station nor involves a complex reconstruction process.

[0005] According to an exemplary embodiment, there is provided an electronic system for estimating a subject's arterial blood pressure, comprising: a heartbeat detection module configured for receiving an ECG signal and detecting a QRS complex of the ECG signal; a PPG sensor module configured for triggering a light emitter and thereby generating a plurality of samples of a PPG signal; a blood pressure calculation module configured for receiving information about the detected QRS complexes and the PPG signal samples and calculate at least one blood pressure value (e.g. systolic and/or diastolic blood pressure values) based on a PAT between the ECG and the PPG signal; wherein the PPG sensor module is further configured for receiving information about the detected QRS complexes, for triggering, each time a QRS complex is detected, the generation of a plurality of samples of a PPG signal and for determining a PPG signal acquisition period.

[0006] According to an exemplary embodiment, the PPG sensor module is configured for triggering the light emitter according to an uniform stimulation pattern, thereby generating a number of uniform samples of the PPG signal during said determined PPG acquisition period.

[0007] According to an exemplary embodiment, the determined PPG signal acquisition period starts when a QRS complex is detected.

[0008] According to an exemplary embodiment, the determined PPG signal acquisition period starts when an R peak is detected.

[0009] According to an exemplary embodiment, the determined PPG signal acquisition period is determined as a time period that is smaller than an average RR interval.

[0010] According to an exemplary embodiment, the determined PPG signal acquisition period is determined as a time period that is half of an average RR interval.

[0011] According to an exemplary embodiment, the determined PPG signal acquisition period is dynamically calculated based on a plurality of heart beat intervals.

[0012] According to an exemplary embodiment, the determined PPG signal acquisition period is determined based on a sum of sample slopes.

[0013] According to an exemplary embodiment, the determined PPG signal acquisition period is determined to finish when the sum of the sample slopes reaches a predetermined threshold.

[0014] According to an exemplary embodiment, the determined PPG signal acquisition period is further determined based on the duration of a plurality of previously determined PPG signal acquisition periods.

[0015] According to an exemplary embodiment, the determined PPG signal acquisition period is determined based on a linear or non-linear combination of the duration of a predetermined number of previously determined PPG signal acquisition periods.

[0016] The invention also relates to an electronic device comprising a system for estimating a subject's arterial blood pressure according to embodiments herein described.

[0017] The invention also relates to a method for estimating a subject's arterial blood pressure comprising: receiving a subject's ECG signal and detecting a QRS complex of said ECG signal; generating a plurality of samples of a PPG signal; receiving information about the detected QRS complexes and the PPG signal samples and calculating at least one blood pressure value based on a PAT between the ECG signal and the PPG signal; wherein the step of generating a plurality of samples of a PPG signal comprises triggering, each time a QRS complex is detected, the generation of a plurality of samples of a PPG signal during a determined PPG signal acquisition period.

[0018] The invention also relates to a computer program product comprising computer program code means adapted to calculate a subject's blood pressure according to the methods herein described when said program is run on a computer, and to a computer readable storage medium comprising such computer program.

[0019] According to an exemplary embodiment, there is provided an ECG assisted BP estimation, enabling ECG assisted PPG acquisition for cuffless blood pressure monitoring.

[0020] While prior art implementations report achieving sufficient accuracy in determining BP for wearable applications, their power consumption is dominated by the PPG system, owing to the uniform stimulation and sampling. Another prior art demonstrated the use of Compressed Sampling based PPG for cuffless BP estimation. However, the proposed solution employs a full signal reconstruction process to perform BP determination from the reconstructed PPG signal, with the assumption of the availability of a powerful base station. The overhead in the reconstruction process can potentially cancel all power savings obtained from CS acquisition of PPG.

[0021] According to an exemplary embodiment, there is provided an event driven approach, that relies on the assistance from ECG to acquire PPG. Realizing that the peak in PPG signal is the after effect of the pumping action of blood through vessels by heart, one can utilize the occurrence of the QRS complex to trigger the capture of the PPG signal. The acquisition can be stopped, when sufficient number of samples are acquired around the peak of the PPG signal. The presence of QRS complexes in the ECG can easily be detected using an activity detection process as outlined in "A 17nA, 47.2dB dynamic range, adaptive sampling controller for online data rate reduction in low power ECG systems" by V. R. Pamula et al., 2016 IEEE Biomedical Circuits and Systems Conference (BioCAS), Oct 2016, pp. 272 - 275. A number of PPG acquisition stopping criteria are then determined for the PPG sampling, ranging from thresholding, sum-of-slopes, learning approaches and/or a combination thereof.

[0022] According to an exemplary embodiment, since, the relative timing information of interest is completely preserved in the ECG assisted acquisition mode, both SBP and DBP are estimated with the same degree of accuracy as in the case of a continuous uniform sampling generation mode.

[0023] According to an exemplary embodiment, the proposed approach retains the relevant relative timing information between the ECG and the PPG signals, yet facilitating accurate BP estimation at a reduced average stimulation and sampling rate.

[0024] According to an exemplary embodiment, the proposed technique can provide more accurate results and can reduce more power consumption depending on the relative placement of the ECG and the PPG sensors.

Brief description of the drawings

[0025] The above and other aspects of the system and method according to the present description will be shown and explained with reference to the non-restrictive example embodiments described hereinafter.

Figure 1A shows a first general block diagram of an exemplary system for blood pressure estimation.

Figure 1B illustrates a pulse arrival time period (PAT) between an ECG and a PPG signal according to an exemplary embodiment.

Figure 2 shows an example of generated PPG signal samples and determined PPG acquisition periods based on ECG QRS signal detection and triggering, according to an exemplary embodiment.

Figure 3 shows another example of PPG samples acquired in ECG assisted PPG acquisition mode.

Figure 4 shows a flow diagram for determining the PPG signal acquisition period and acquisition flow, according to an exemplary embodiment.

Figure 5 shows another flow diagram for determining the PPG signal acquisition period according to an exemplary embodiment.

Figure 6 shows a flow diagram for determining the PPG signal acquisition period with a sum of slopes stopping criteria, according to an exemplary embodiment.

Figure 7 shows a flow diagram for determining the PPG signal acquisition period with a learning based stopping criteria, according to an exemplary embodiment.

Detailed description

[0026] 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.

[0027] **Figure 1A** shows a first general block diagram of an exemplary system **100** for blood pressure estimation comprising: a heartbeat detection module **10** configured for receiving an electrocardiogram signal **S1** and detecting a QRS complex of said electrocardiogram signal; a PPG sensor module **20** configured for triggering a light emitter and thereby generating a plurality of samples of a PPG signal **S3** and a blood pressure calculation module **30** configured for receiving information about the detected QRS complexes **S2** and the PPG signal samples **S3** and calculate at least one blood pressure value **SBP, DBP** based on a pulse arrival time period between the ECG and the PPG signal (as illustrated in **Figure 1B).**

[0028] The determination of BP is based on the relative timing between peaks in the ECG and PPG signals. **Figure 1B** shows the relevant timing information required for the BP estimation. Of interest is the pulse arrival time (PAT), which is the temporal difference between the peak in the ECG to the subsequent peak in the PPG signal. Once PAT is determined, BP can be estimated using the following equations:

$$SBP = a1\_PAT + b1\_HR + c1$$

$$DBP = a2\_PAT + b2\_HR + c2$$

[0029] where SBP and DBP are the systolic and diastolic blood pressure respectively, while ai, bi and ci, for i = 1; 2 are the calibration coefficients obtained through linear regression.

[0030] According to an exemplary embodiment, the PPG sensor module **20** is further configured for receiving information about the detected QRS complexes **S2,** for triggering, each time a QRS complex is detected, the generation of a plurality of samples of a PPG signal and for determining a PPG signal acquisition period.

[0031] **Figures 2 and 3** show examples of generated PPG signal samples **S31 to S34** and determined PPG acquisition periods **PT1 to P74** based on ECG QRS signal detection and triggering. According to an exemplary embodiment, the PPG sensor module **20** is configured for triggering the light emitter, e.g. a LED, according to an uniform stimulation pattern, thereby generating a number of uniform samples (the dots in the sets of PPG samples **S31 to S34** in **Figure 2** and the circumferences in the sets PPG of samples **S31 to S34** in **Figure 3)** of the PPG signal during each determined PPG acquisition period **PT1 to PT4.** According to an exemplary embodiment, the PPG signal acquisition periods start when a QRS complex, e.g. an R peak in the ECG signal, is detected. According to an exemplary embodiment, the PPG signal acquisition periods may be fixed or variable, depending on the PPG acquisition stopping criteria applied in the PPG sensor module **20.**

[0032] **Figure 4** shows a flow diagram for determining the PPG signal acquisition period and acquisition flow, according to an exemplary embodiment. When a QRS complex is detected the PPG acquisition is initiated, e.g. by stimulating the LED in the PPG sensor module **20,** so that uniform PPG samples are generated and provided to the blood pressure calculation module **30.** According to an exemplary embodiment, the PPG acquisition period is finished based on a stopping criteria which can be fixed or dynamically determined. According to an exemplary embodiment, a method for estimating a subject's arterial blood pressure comprises: receiving a subject's ECG signal and detecting a QRS complex of said ECG signal; generating a plurality of samples of a PPG signal; receiving information about the detected QRS complexes **S2** and the PPG signal samples and calculating at least one blood pressure value based on a PAT between the ECG signal and the PPG signal; wherein the step of generating a plurality of samples of a PPG signal comprises triggering, each time a QRS complex is detected, the generation of a plurality of samples **S31 to S34** of a PPG signal during a determined PPG signal acquisition period **PT1 to PT4.**

[0033] **Figure 5** shows another flow diagram for determining the PPG signal acquisition period according to an exemplary embodiment. According to an exemplary embodiment, the determined PPG signal acquisition period is determined as a time period that is smaller than an average RR interval. According to an exemplary embodiment, the determined PPG signal acquisition period is determined as a time period that is half of an average RR interval. According to an exemplary embodiment, the determined PPG signal acquisition period may be a fixed or a variable time period. According to an exemplary embodiment, the determined PPG signal acquisition period may be dynamically calculated based on a plurality of heart beat RR intervals or HR information.

[0034] **Figure 6** shows a flow diagram for determining the PPG signal acquisition period with a sum of slopes stopping criteria, according to an exemplary embodiment. According to an exemplary embodiment, the PPG signal acquisition will continue as long as the sum of the instantaneous slopes of the PPG samples is greater than a certain threshold. It shall be noted that this is just an

example, and further stopping criteria can be generated based on the sum of the slopes of the generated PPG samples. Advantageously, this PPG signal acquisition period determination takes in consideration the form of the PPG signal and assures more accurate results.

[0035] **Figure 7** shows a flow diagram for determining the PPG signal acquisition period with a learning based stopping criteria, according to an exemplary embodiment. According to an exemplary embodiment, the determined PPG signal acquisition period may be further determined based on the duration of a plurality of previously determined PPG signal acquisition periods. According to an exemplary embodiment, the determined PPG signal acquisition period is determined based on a linear or non-linear combination of the duration of a predetermined number of previously determined PPG signal acquisition periods.

[0036] It shall be noted that the system **100** for blood pressure estimation according to embodiments of the invention may be implemented according to hardware and/or software state of the art techniques, comprising for example a microprocessor, microcontroller or digital signal processor that can understand and execute software program instructions. Some programmable hardware logic and memory means may be specifically designed also for executing the method or parts of it according to exemplary embodiments of the invention.

Claims

1. An electronic system (100) for estimating a subject's arterial blood pressure, comprising:

a heartbeat detection module (10) configured for receiving an electrocardiogram signal (S1) and detecting a QRS complex of said electrocardiogram signal;
a photoplethysmographic sensor module (20) configured for triggering a light emitter and thereby generating a plurality of samples of a photoplethysmographic signal (S3);
a blood pressure calculation module (30) configured for receiving information about the detected QRS complexes (S2) and the photoplethysmographic signal samples (S3) and calculate at least one blood pressure value (SBP, DBP) based on a pulse arrival time period (PAT) between the electrocardiogram and the photoplethysmographic signal;
characterized in that
the photoplethysmographic sensor module (20) is further configured for receiving information about the detected QRS complexes (S2), for triggering, each time a QRS complex is detected, the generation of a plurality of samples of a photoplethysmographic signal (S31 to S34) and for determining a photoplethysmographic signal acquisition period (PT1 to PT4).

2. A system (100) for estimating a subject's arterial blood pressure according to claim 1 wherein the photoplethysmographic sensor module (20) is configured for triggering the light emitter according to an uniform stimulation pattern, thereby generating a number of uniform samples (S31 to S34) of the photoplethysmographic signal during said determined photoplethysmographic acquisition period (PT1 to PT4).

3. A system (100) for estimating a subject's arterial blood pressure according to any preceding claim wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) starts when a QRS complex is detected.

4. A system (100) for estimating a subject's arterial blood pressure according to claim 3 wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) starts when an R peak is detected

5. A system (100) for estimating a subject's arterial blood pressure according to any preceding claim wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) is determined as a time period that is smaller than an average RR interval.

6. A system (100) for estimating a subject's arterial blood pressure according to claim 5 wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) is determined as a time period that is half of an average RR interval.

7. A system (100) for estimating a subject's arterial blood pressure according to any preceding claim wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) is dynamically calculated based on a plurality of heart beat intervals.

8. A system (100) for estimating a subject's arterial blood pressure according to any of claims 1 to 4 wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) is determined based on a sum of sample slopes.

9. A system (100) for estimating a subject's arterial blood pressure according to claim 8 wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) is determined to finish when the sum of the sample slopes reaches a predetermined threshold.

10. A system (100) for estimating a subject's arterial blood pressure according to any of the previous

claims wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4) is further determined based on the duration of a plurality of previously determined photoplethysmographic signal acquisition periods.

11. A system (100) for estimating a subject's arterial blood pressure according to claim 10 wherein the determined photoplethysmographic signal acquisition period (PT1 to PT4 is determined based on a linear or non-linear combination of the duration of a predetermined number of previously determined photoplethysmographic signal acquisition periods.

12. Electronic device comprising a system (100) for estimating a subject's arterial blood pressure according to any preceding claim.

13. A method for estimating a subject's arterial blood pressure comprising:

receiving a subject's electrocardiogram signal (S1) and detecting a QRS complex of said electrocardiogram signal;
generating a plurality of samples of a photoplethysmographic signal (S3);
receiving information about the detected QRS complexes (S2) and the photoplethysmographic signal samples (S3) and calculating at least one blood pressure value (SBP, DBP) based on a pulse arrival time period (PAT) between the electrocardiogram signal and the photoplethysmographic signal;
characterized in that
the step of generating a plurality of samples of a photoplethysmographic signal (S3) comprises triggering, each time a QRS complex is detected, the generation of a plurality of samples of a photoplethysmographic signal (S31 to S34) during a determined photoplethysmographic signal acquisition period (PT1 to PT4).

14. A computer program product comprising computer program code means adapted for calculating a subject's arterial blood pressure according to the method of claim 13 when said program is run on a computer.

15. A computer readable storage medium comprising a computer program according to claim 14.

Figure 1A

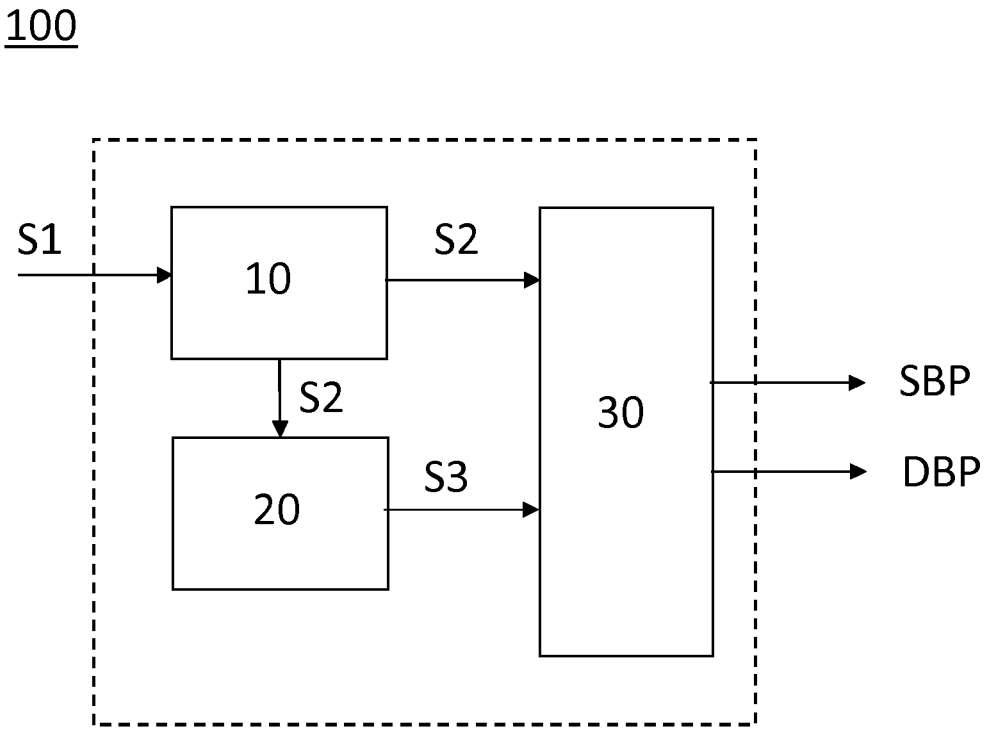


Figure 1B

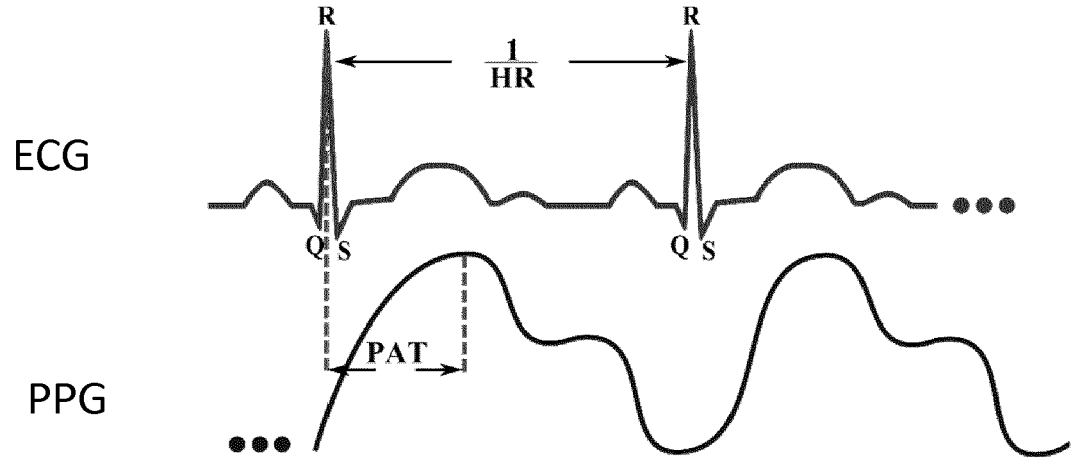


Figure 2

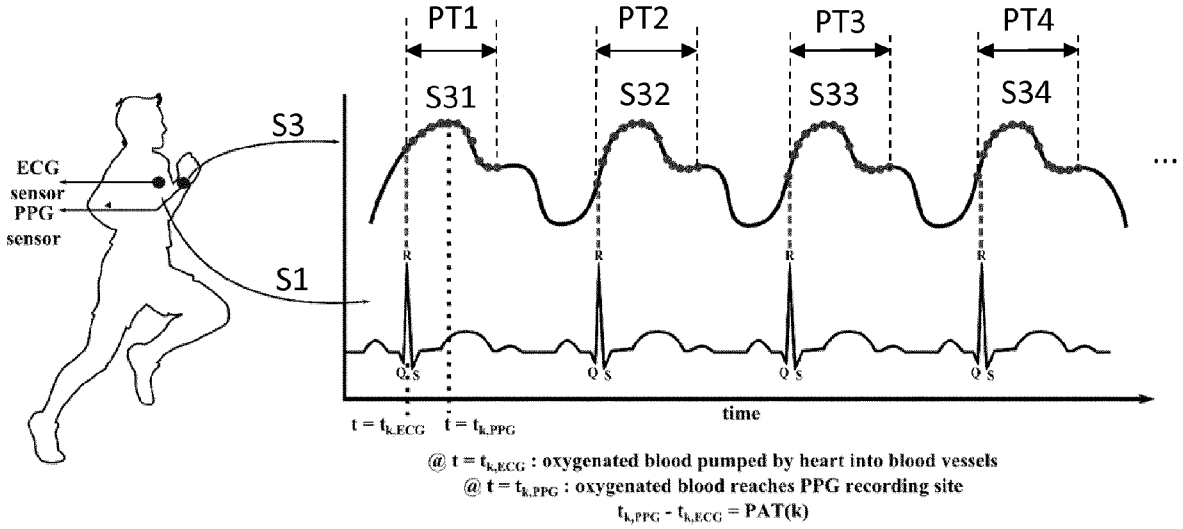


Figure 3

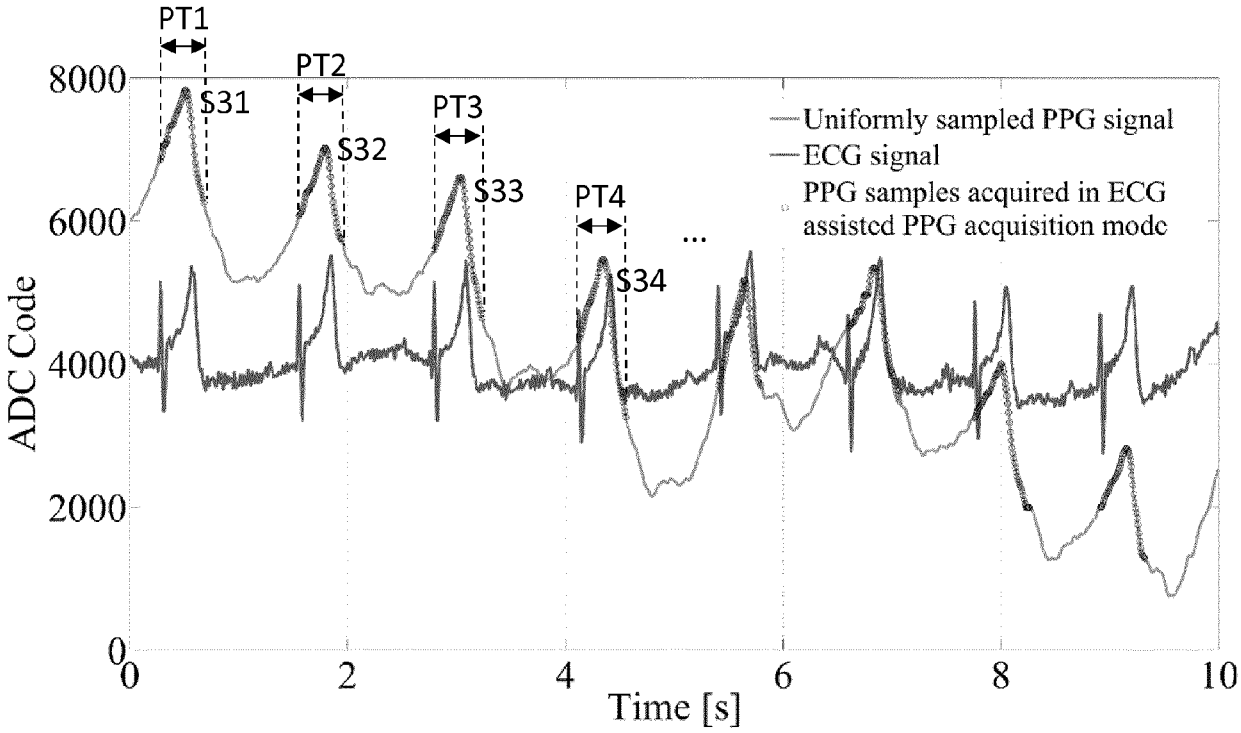


Figure 4

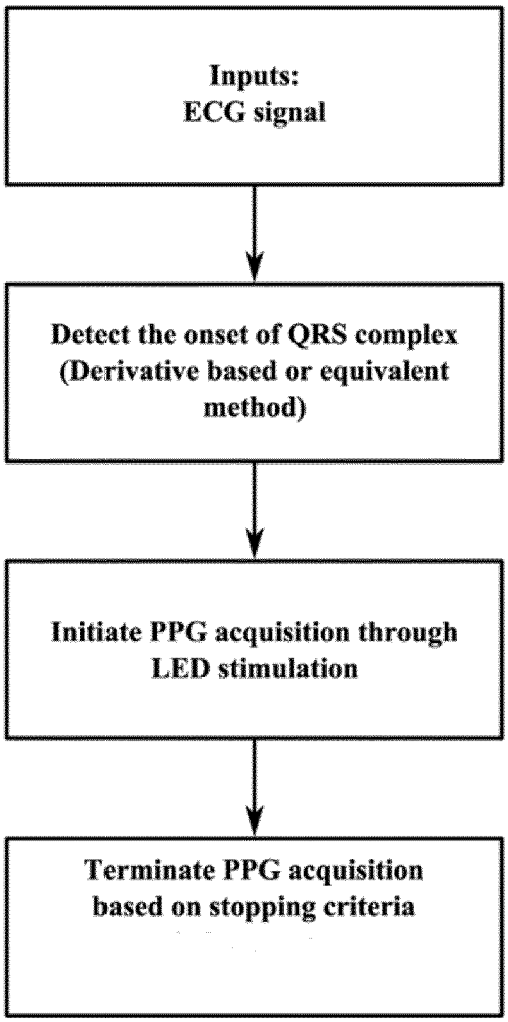

Inputs:
ECG signal
Detect the onset of QRS complex (Derivative based or equivalent method)
Initiate PPG acquisition through LED stimulation
Terminate PPG acquisition based on stopping criteria

Figure 5

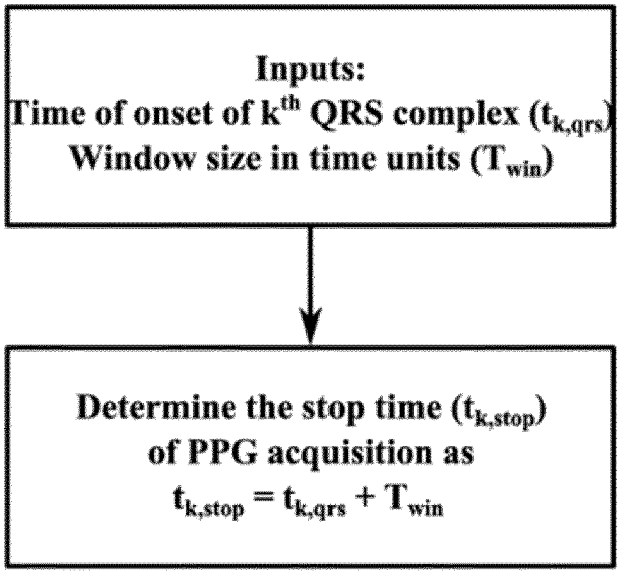

Inputs:
Time of onset of k^th QRS complex (t_k,qrs)
Window size in time units (T_win)
Determine the stop time (t_k,stop)
of PPG acquisition as
t_k,stop = t_k,qrs + T_win

Figure 6

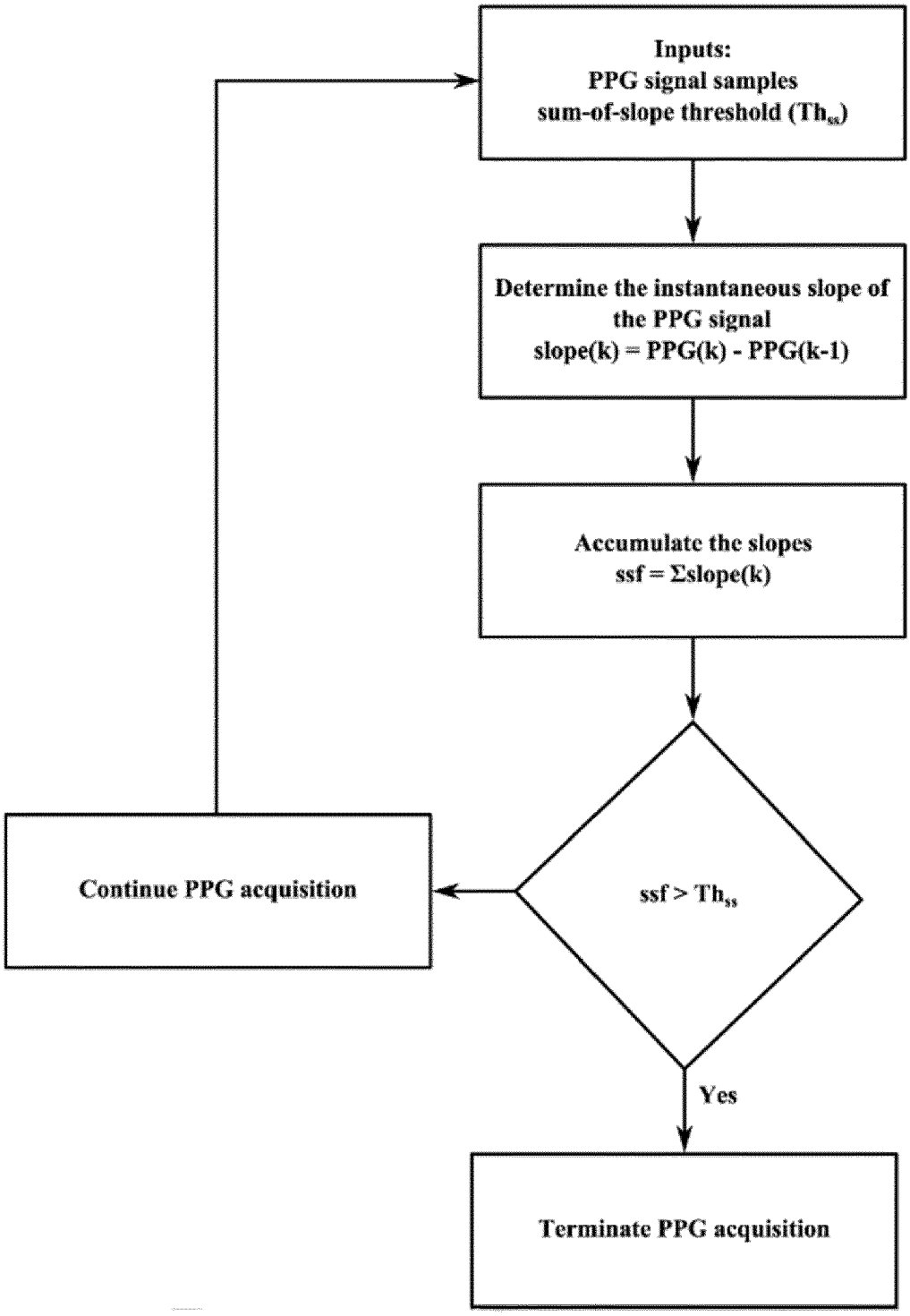
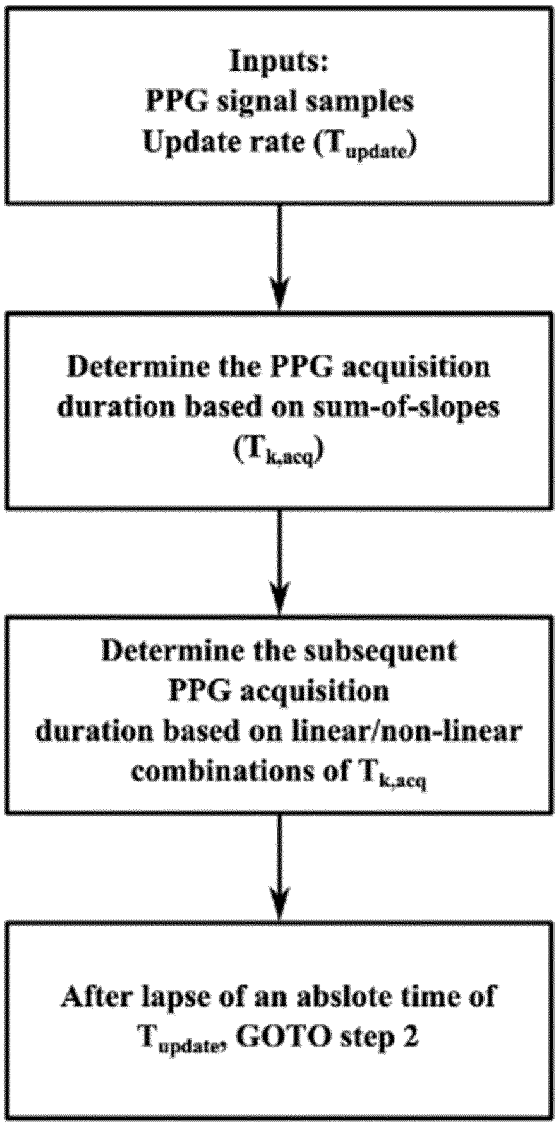

Inputs:
PPG signal samples
sum-of-slope threshold (Th_{ss})
Determine the instantaneous slope of the PPG signal
slope(k) = PPG(k) - PPG(k-1)
Accumulate the slopes
ssf = Σslope(k)
ssf > Th_{ss}
Continue PPG acquisition
Yes
Terminate PPG acquisition

Figure 7


Inputs:
PPG signal samples
Update rate (T_{update})
Determine the PPG acquisition duration based on sum-of-slopes ($T_{k,acq}$)
Determine the subsequent PPG acquisition duration based on linear/non-linear combinations of $T_{k,acq}$
After lapse of an abslote time of T_{update}, GOTO step 2

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EUROPEAN SEARCH REPORT

Application Number
EP 18 02 0124

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	US 2010/324384 A1 (MOON JIM [US] ET AL) 23 December 2010 (2010-12-23) * paragraph [0017] * * paragraph [0068] - paragraph [0069] * * paragraph [0072] - paragraph [0075] * * paragraph [0089] - paragraph [0096] * * paragraph [0119] - paragraph [0125] * * figures 6,7,13A-D,19-23B *	1-15	
A	US 2010/081946 A1 (GARUDADRI HARINATH [US] ET AL) 1 April 2010 (2010-04-01) * paragraph [0008] * * paragraph [0083] - paragraph [0087] * * paragraph [0094] * * figures 5-7A *	1-15	TECHNICAL FIELDS SEARCHED (IPC) A61B
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	26 July 2018	Görlach, Tobias

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 02 0124

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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26-07-2018

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专利名称(译)	用于无袖血压估计的系统和方法		
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摘要(译)

一种用于估计受试者的动脉血压的电子系统（100），包括：心跳检测模块（10），被配置为接收心电图信号（S1）并检测所述心电图信号的QRS波群; PPG传感器模块（20），被配置为触发光发射器，从而产生PPG信号的多个样本（S3）;血压计算模块（30），被配置为接收关于检测到的QRS波群（S2）和PPG信号样本（S3）的信息，并基于脉冲到达时间段（PAT）计算至少一个血压值（SBP，DBP）心电图和PPG信号之间;其中，PPG传感器模块（20）还被配置用于接收关于检测到的QRS复合波的信息（S2），用于在每次检测到QRS波群时触发PPG信号的多个样本的生成（S31至S34）并且用于确定PPG信号获取周期（PT1至PT4）。