(54) **METHOD FOR DETECTING QRS COMPLEX OF ELECTROCARDIOGRAM SIGNAL**

(57) The subject of the invention is a method of detecting a QRS complex in an electrocardiogram (ECG) signal, which can be used in biomedical diagnostics. In the method according to the invention, an ABS_DIFF_SHORT signal generated on an output of an ABS_DIFF_SHORT_MODULE module, which is the difference of the current instantaneous value of the ECG signal provided by an ECG_MODULE measuring module, and the mean value of a SHORT_AVG of the ECG signal calculated for a time interval T_SHORT, are monitored using the COMP comparator. Then, the COMP comparator detects the moment when an ABS_DIFF_SHORT signal reaches a threshold TH value previously determined with a TH_MODULE module, and then, when the ABS_DIFF_SHORT signal reaches the threshold TH value, the countdown of a SEARCHING_WINDOW time window starts with a PULSE_GENERATOR pulse generator which has fixed-length for search for a R wave in the QRS complex of the ECG signal. In the next step, using a PEAK_DETECTOR detection module, the maximum value of the ABS_DIFF_LONG_MODULE module produced at its output is recorded during the SEARCHING_WINDOW time window of the ABS_DIFF_LONG signal, which is the difference of the current instantaneous value of the ECG signal and the average LONG_AVG value of the ECG signal calculated for a segment of a T_LONG time segment while the PEAK_DETECTOR detection module the moment of the detected maximum value of the ABS_DIFF_LONG signal is recorded during the SEARCHING_WINDOW time window. After that, the maximum value of the ABS_DIFF_LONG signal detected by the PEAK_DETECTOR detection module is stored by means of a R_AMPLITUDE_MEMORY memory module, which is considered to be the R-wave amplitude in the QRS complex.

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Description

[0001]   The subject of the invention is a method for detecting the QRS complex of an electrocardiogram (ECG) signal applicable in biomedical diagnostics.

[0002]   A device for monitoring the ECG signal, consisting of technical means for measuring the pulse, filters and amplifiers for noise elimination and amplification of the diagnostically useful signal, and a computer programmed to suppress frequency components below 15 Hz and above 25 Hz and amplify the R wave in the QRS signal is known from the patent description US5738104.

[0003]   A heart rate monitor for calculating heart rate based upon ECG signals. The monitor preferably utilizes 3 electrodes to pick up ECG signals and a differential amplifier to cancel common mode signals in the output of the electrode. An analog bandpass filter comprised a low pass and high pass filter in series each with different rolloffs filters out low and high frequency components. The signals are digitized and digital filtering to remove power line hum and remnants of low and high frequency noise is performed. Then the ECG signals are digitally enhanced by differentiating and squaring the results of the differentiator then being averaged in a moving average computation so as to generate enhanced digital data. The enhanced digital data is then processed to learn the ECG characteristics, and a heart rate arbitrator processes the incoming signals to select out actual ECG complexes from EMG noise and other noise. The ECG isolation process is done using rules of reason and the learned characteristics of the ECG signal.

[0004]   A device and method is known from US5188116 patent for electrocardiographic tests, the device of which is a system for the analysis of electrocardiographic activity for the detection of ischemic heart disease, consisting of tools for detecting a multiplicity of periodic electrocardiographic signals, a memory unit storing these signals, a microprocessor capable of calculating collective cycles for each signal, detecting and storing signal amplitude characteristics, as well as determining the variance of the signals and modifying them, furthermore from technical means for determining the degree of coronary artery disease. The patent also describes a method of analyzing electrocardiographic activity for the detection of ischemic heart disease, including collecting and storing electrocardiographic signals, establishing a cumulative cycle for each signal, determining the variance of each signal and the total variability of all signals, and then determining the size of the coronary heart disease therefrom.

[0005]   There is known from the US patent US9414761 a method of processing electrocardiographic signals comprising filtering the ECG signal by passing the ECG signal through at least one first low-pass filter and a high-pass filter, obtaining a processed ECG signal by passing the trailing averages of the ECG signal envelope through a second lowpass filter, identifying a search region in the processed ECG signal, the search region being the time interval between two local peaks of the processed ECG signal, and identifying the maximum amplitude pulse within the search region in processed ECG signal that is considered to be the R wave in the QRS complex of the ECG signal.

[0006]   A method is known from the article "A Real-Time QRS Detection Algorithm", IEEE Transactions on Biomedical Engineering, vol. 32, no. 3, 1985, by J. Pan, W. J. Tompkins for detecting the QRS complex of the electrocardiogram (ECG) signal, including the reception of the ECG signal obtained by means of an ECG recorder, filtering the ECG signal by passing the ECG signal through a low-pass filter and then a high-pass filter with parameters selected in such a way that both filters jointly create a band-pass filter, extracting information about the slope of the QRS complex of the ECG signal by passing the ECG signal after filtering through the differential system, then emphasizing information about the slopes of the QRS complex by squaring the resulting signal, then calculating average value of the resulting signal for a time interval of a fixed length until the threshold has been exceeded, which is considered equivalent to detecting the R-wave in the QRS complex, resulting in an adaptation of the threshold, and a re-comparison of the signal values after a time interval of 200 ms.

[0007]   The following terms have been introduced in current description as below:

(1) ECG_MODULE - an electrocardiogram (ECG) signal measurement module,

(2) ABS_DIFF_SHORT_MODULE - a module that determines the ABS_DIFF_SHORT signal, which is a difference between a current instantaneous value of the ECG signal and the average SHORT_AVG value of the ECG signal calculated for a T_SHORT time interval of a fixed length,

(3) ABS_DIFF_LONG_MODULE - a module that determines the ABS_DIFF_LONG signal, which is a difference between a current instantaneous value of the ECG signal and the average LONG_AVG value of the ECG signal calculated for a T_LONG time interval of a fixed length,

(4) COMP - a comparator,

(5) PEAK_DETECTOR - a detector of the maximum value of the ABS_DIFF_LONG signal during the SEARCHING_WINDOW time window for searching of a R wave in the QRS complex,

(6) PULSE GENERATOR - a pulse generator which, when a triggering signal arrives, generates a pulse of a fixed duration equal to the SEARCHING_WINDOW time window for searching (poszukujemy za̶ł, amka nie w za̶ł, amku - for

powinno zostac) the R wave in the QRS complex of the ECG signal,

(7) TH_MODULE - a module that determines the threshold TH value for the ABS_DIFF_SHORT signal, used to determine the beginning of the SEARCHING_WINDOW time window for searching the R wave in the QRS complex of the ECG signal,

(8) R_AMPLITUDE_MEMORY - a memory module for storing information about the amplitudes of the maximum values of the LONG_ABS_DIFF signal in subsequent cycles of the ECG signal, which are considered to be the amplitudes of the R waves in subsequent QRS complexes of the ECG signal,

(9) R_TIMESTAMP_MEMORY - a memory module for storing information about the times of the maximum LONG_ABS_DIFF signal values in the subsequent cycles of the ECG signal, which are considered to be the times of the R waves in subsequent QRS complexes of the ECG signal.

[0008]   According to the invention, a method for detecting the QRS complex of the electrocardiogram (ECG) signal consisting in a reception of the ECG signal obtained by a ECG signal measurement module monitoring an electrical activity of a patient's heart is characterized in that a COMP comparator monitors the ABS_DIFF_SHORT signal generated at the ABS_DIFF_SHORT_MODULE output, said signal being a difference of a current instantaneous value of the ECG signal provided by the ECG_MODULE measurement module, and an average SHORT_AVG value of the ECG signal calculated for a T_SHORT time segment of a fixed length. Then, using the COMP comparator, a moment when the ABS_DIFF_SHORT signal reaches a threshold TH value, previously determined by the TH_MODULE module, is detected, thereafter, as soon as the ABS_DIFF_SHORT signal reaches a predetermined threshold TH value, the timing of the SEARCHING_WINDOW time window of a predetermined length to search for a R wave in the QRS complex of the ECG signal is started by the impulse generator PULSE GENERATOR. In the next step, using the PEAK_DETECTOR detection module, the maximum value of the ABS_DIFF_LONG signal produced on the output of the ABS_DIFF_LONG_MODULE module, whereas ABS_DIFF_LONG signal is a difference of a current instantaneous value of the ECG signal and an average LONG_AVG value of the ECG signal calculated per fixed-length T_LONG time interval, is recorded during the SEARCHING_WINDOW time window, and at the same time, the time of occurrence of the detected maximum value of the ABS_DIFF_LONG signal during the SEARCHING_WINDOW time window is recorded with the PEAK_DETECTOR detection module. After these operations, the maximum value of the ABS_DIFF_LONG

signal detected by the PEAK_DETECTOR detection module, which is considered to be the amplitude of the R wave in the QRS complex, is stored by means of the memory module R_AMPLITUDE_MEMORY.

[0009]   Then, the time of the occurrence of the maximum value of the ABS_DIFF_LONG signal detected by the PEAK_DETECTOR detection module, which is considered to be the time of the occurrence of the R wave in the QRS complex, is stored by means of the R_TIMESTAMP_MEMORY memory module.

[0010]   In the next step, using the TH_MODULE module, a new threshold TH value is determined, which is used to trigger the beginning of the SEARCHING_WINDOW time window in the next cycle of the ECG signal with the PULSE GENERATOR impulse generator. The new TH value threshold is determined on the basis of the maximum values of the ABS_DIFF_LONG signal in the previous ECG signal cycles detected by the PEAK_DETECTOR detection module and stored with the R_AMPLITUDE_MEMORY memory module. Then, the monitoring of the ABS_DIFF_SHORT signal generated at the output of the ABS_DIFF_SHORT_MODULE module on the basis of the ECG signal provided by the ECG signal measuring module is resumed by means of the COMP comparator. After that, the entire cycle described above is repeated as many times as required.

[0011]   The T_SHORT time period, used to determine the SHORT_AVG average value of the ECG signal, is not shorter than 40 ms and also not longer than 100 ms, while the T_LONG time period, used to determine the LONG_AVG average value of the ECG signal, is not shorter than 150 ms and also not longer than 400 ms.

[0012]   The TH value threshold for the ABS_DIFF_SHORT signal, which is the difference between the current instantaneous value of the ECG signal provided by the ECG_MODULE measurement module, and the average SHORT_AVG value of the ECG signal calculated for the T_SHORT time interval of fixed length, in a given detection cycle of the QRS complex, is determined by the TH_MODULE module. This is done on the basis of the TH threshold value determined by the TH_MODULE module in the previous QRS complex detection cycle and recorded with the PEAK_DETECTOR detection module, and the R-wave amplitude stored in the R_AMPLITUDE_MEMORY memory module in the QRS complex recorded in the current QRS complex detection cycle. The TH threshold in a given QRS complex detection cycle is the sum of the product of the TH threshold value in the previous QRS detection cycle and the scaling factor less than unity and the product of the R-wave amplitude recorded in the current QRS complex detection cycle, one minus the scaling factor, and the weighting factor also less than one. The threshold TH value before the first detection cycle of the QRS complex is determined by the TH_MODULE module in a form of the product of the weighting factor that is less than one and the average value of the ECG signal calculated for

a time interval of one second.

[0013] The method for detecting the QRS complex in the electrocardiogram signal by referring, through the subtraction of the current instantaneous value of the ECG signal from its average values, calculated respectively for the T_SHORT and T_LONG time segments is immune to noise and disturbances occurring during the measurement of the electrocardiogram signal. In addition, thanks to a continuous adjustment of the TH threshold value - by means of the TH_MODULE module - used to determine the beginning of the SEARCHING_WINDOW time window for searching the R wave in the QRS complex, to the TH threshold value determined in the previous QRS detection cycle and to the amplitude of the R wave in the current QRS detection cycle, the R wave detection sensitivity to transient fluctuations in the maximum range of changes of the electrocardiogram signal that may occur during the measurement of the ECG signal, is reduced.

[0014] The electrocardiogram (ECG) signal, representing the electrical activity of the patient's heart, is received with the ECG_MODULE measurement module via electrodes attached to the patient's body. The ECG signal can be reduced to a sequence of positive and negative deviations (waves) from the isoelectric line, which corresponds to the periods of time during which no heart beats are detected. The group of the largest waves, called the QRS complex, consists of a negative deflection (Q wave), a positive deflection (R wave), and another negative deflection (S wave). The R wave has usually the highest amplitude in the QRS complex. The detection of the QRS complex is often reduced to the detection of the R wave. Statistics of the intervals between the R waves and the amplitudes of the R waves are important diagnostic information, used in medicine, among other things, to diagnose the work of the heart.

[0015] According to the invention, when detecting each QRS complex in the ECG signal with the ABS_DIFF_SHORT_MODULE module, the ABS_DIFF_SHORT signal is determined on the basis of the ECG signal, which is the difference of the current instantaneous value of the ECG signal and the average SHORT_AVG value of the ECG signal calculated for the T_SHORT time interval of 55 ms. At the same time, the ABS_DIFF_LONG_MODULE module determines the ABS_DIFF_LONG signal, which is the difference between the current instantaneous value of the ECG signal and the average LONG_AVG value of the ECG signal calculated for the T_LONG time interval of 277 ms. Monitoring of the ABS_DIFF_SHORT signal is aimed at detecting the beginning of the rising edge of the ECG signal preceding the occurrence of the R wave in the QRS complex, and subtracting the current value of the ECG signal from the average SHORT_AVG value is aimed at filtering out any noise and disturbances present in the ECG signal received by the ECG_MODULE measuring module. The lengths of the time segments, T_SHORT and T_LONG, respectively, result from the dynamics of the human heart.

[0016] The SHORT_ABS_DIFF signal available at the output of the ABS_DIFF_SHORT_MODULE module is continuously compared by means of a COMP comparator with a predetermined TH value threshold determined by the TH_MODULE module. The detection of the SHORT_ABS_DIFF signal reaching a predetermined TH threshold value is taken to be the start of the rising edge of the ECG signal preceding the occurrence of the R wave in the QRS complex. When it is detected that the SHORT_ABS_DIFF signal has reached the predetermined TH threshold, the COMP comparator, with the help of an appropriate signal on its output, starts generating a 200 ms long pulse using the PULSE GENERATOR pulse generator, which determines the SEARCHING_WINDOW time window, during which the R wave is searched for in the QRS complex of the ECG signal. The pulse generated at the output of the PULSE GENERATOR pulse generator activates the PEAK_DETECTOR module with its active logic level, which records the maximum value of the LONG_ABS_DIFF signal generated at the output of the ABS_DIFF_LONG_MODULE module during the SEARCHING_WINDOW time window. Subtracting the current value of the ECG signal from the average value of LONG_AVG is designed to filter out possible noise and disturbances in the ECG signal received by the ECG_MODULE measurement module.

[0017] The PEAK_DETECTOR module also records a moment when the detected maximum value of the ABS_DIFF_LONG signal which occurred during the SEARCHING_WINDOW time window.

[0018] The maximum value of the ABS_DIFF_LONG signal produced at the output of the ABS_DIFF_LONG_MODULE module during the SEARCHING_WINDOW time window is considered to be the R-wave amplitude in the QRS complex of the ECG signal. In turn, the moment of occurrence of the detected maximum value of the LONG_ABS_DIFF signal during the SEARCHING_WINDOW time window is considered to be the moment of the R wave occurrence in the QRS complex of the ECG signal. Then, when the trailing edge of the pulse generated at the output of the pulse generator PULSE GENERATOR occurs, the maximum value of the LONG_ABS_DIFF signal previously detected by PEAK_DETECTOR module is recorded by means of the module R_AMPLITUDE_MEMORY, and the moment of the maximum signal value of the LONG_ABS_DIFF signal is recorded by means of the R_AMPLITUDE_MEMORY module respectively.

[0019] Then, by means of the TH_MODULE module, a new threshold TH value is determined, which serves for detection of the beginning of the SEARCHING_WINDOW time window by means of a PULSE GENERATOR pulse generator. The new TH value threshold is determined on the basis of the threshold TH value determined by the TH_MODULE module in the previous QRS detection cycle recorded with the

PEAK_DETECTOR detection module and the R-wave amplitude stored in the R_AMPLITUDE_MEMORY memory module in the QRS complex in the current QRS complex detection cycle in such a way that the TH value threshold in a given QRS complex detection cycle is the sum of the product of the TH threshold value determined in the previous QRS complex detection cycle and the scaling factor less than one and the product of the R wave amplitude recorded in the current QRS complex detection cycle, one minus the scaling factor, and a weight factor also smaller than one, wherein the TH threshold value before the first detection cycle of the QRS complex is determined by the TH_MODULE module in the form of a the product of less than one weighting factor and the maximum value of the ECG signal over a time interval of one second.

[0020] The above-mentioned rule for determining a new TH threshold value using the TH_MODULE module corresponds to the following mathematical formula:

$$TH_i = \gamma TH_i - 1 + \alpha(1 - \gamma)R_i$$

where γ <1 means the scaling factor, α <1 means the weighting factor, THi means the TH threshold value determined in the current QRS complex detection cycle, THi - 1 means the TH threshold value determined in the previous QRS complex detection cycle, Ri means the R-wave amplitude recorded in the current QRS complex detection cycle, and

$$TH0 = \alpha R_0$$

where TH0 is the threshold value determined prior to the first detection cycle of the QRS complex, and R0 is the maximum value of the ECG signal during one second.

[0021] Then, again, using the COMP comparator, the value of the ABS_DIFF_SHORT signal generated at the output of the ABS_DIFF_SHORT_MODULE module is compared with the new threshold TH value determined in this way on the basis of the ECG signal provided by the ECG_MODULE 1 of the ECG measurement module, and the cycle is repeated.

Claims

1. Method for detecting a QRS complex of an electro-cardiogram (ECG) signal consisting in a reception of the ECG signal obtained by means of an ECG signal measuring module, monitoring the electrical heart activity of the patient, **characterized in that** an ABS_DIFF_SHORT signal generated at an output of an ABS_DIFF_SHORT_MODULE module is monitored using a COMP comparator, where said ABS_DIFF_SHORT signal is the difference between the current instantaneous value of the ECG signal,

provided by an ECG_MODULE measurement module, and an average SHORT_AVG value of the ECG signal calculated for a T_SHORT time segment of a fixed length, then, by means of the COMP comparator, a moment when the ABS_DIFF_SHORT signal reaches a predetermined threshold TH value, determined by a TH_MODULE module, is detected, then, when a moment the ABS_DIFF_SHORT signal reaches the set threshold TH value, a countdown of a SEARCHING_WINDOW time window with a set length for a search for an R wave in the QRS complex of the EKG signal begins using a PULSE GENER-ATOR pulse generator, then a maximum value of the ABS_DIFF_LONG_MODULE produced on the output of a ABS_DIFF_LONG_MODULE module is recorded during the SEARCHING_WINDOW time window of the ABS_DIFF_LONG signal, using a PEAK_DETECTOR detection module, where said ABS_DIFF_LONG signal being the difference between the current instantaneous value of the ECG signal and a LONG_AVG average value of the ECG signal calculated for a T_LONG time segment of a fixed length and, at the same time, using the PEAK_DETECTOR detection module, the moment of occurrence of the detected maximum value of the ABS_DIFF_LONG signal during the SEARCHING_WINDOW time window is registered, then an R_AMPLITUDE_MEMORY memory module saves the maximum value of the ABS_DIFF_LONG signal, detected by the PEAK_DETECTOR detection module, which is considered to be the R wave amplitude in the QRS complex, and then an R_TIMESTAMP_MEMORY memory module records the moment of occurrence of the maximum value of the/a LONG_ABS_DIFF (czy to to samo co ABS_DIFF_LONG) signal detected by the PEAK_DETECTOR detection module, where said LONG_ABS_DIFF value is considered to be the time of the R wave in the QRS complex, then, using the TH_MODULE module, a new TH threshold value is determined used to measure, using the PULSE_GENERATOR pulse generator, the beginning of the SEARCHING_WINDOW time window in the next cycle of the ECG signal, whereas the new TH threshold value is determined on the basis of the ABS_DIFF_SHORT signal maximum values detected by the PEAK_DETECTOR detection module and stored by the R_AMPLITUDE_MEMORY memory module of maximum values of ABS_DIFF_LONG values in the previous ECG signal cycles, followed by a return to monitoring using the COMP signal comparator of the ABS_DIFF_SHORT signal, generated on the output of the ABS_DIFF_SHORT_MODULE module on the basis of the ECG signal provided by the measuring module of the ECG signal, and then the entire cycle described above is repeated as many times as desired.

2. The method according to claim 1, **characterized in that** the T_SHORT time interval for determining the average value of the SHORT_AVG of the ECG signal is not shorter than 40 ms and also not longer than 100 ms, while the T_LONG time interval for determining the LONG_AVG average value of the ECG signal is not shorter than 150 ms and not longer than 400 ms.

3. The method according to claim 1, **characterized in that** the threshold TH value for the ABS_DIFF_SHORT signal, being the difference between the current instantaneous value of the ECG signal provided by the ECG_MODULE measurement module, and the mean SHORT_AVG value of the ECG signal calculated for the fixed length T_SHORT time interval in a given QRS complex detection cycle is determined by the TH_MODULE module based on the TH value threshold determined by the TH_MODULE module in the previous detection cycle of the QRS complex and the R-wave amplitude in the QRS complex registered in the current detection cycle of the QRS complex recorded with the PEAK_DETECTOR detection module and stored in the R_AMPLITUDE_MEMORY memory module, in such a way that the TH value threshold in a given detection cycle of the QRS complex is the sum of the product of the threshold TH value determined in the previous detection cycle of the QRS complex and the less than one scaling factor and the product of the R-wave amplitude recorded in the current QRS complex detection cycle, one minus the scaling factor, wherein the threshold TH value before the first detection cycle of the QRS complex is determined by the TH_MODULE module in the form of a product of less than one weighting factor and the maximum value of the ECG signal calculated for a time interval of one second.

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EUROPEAN SEARCH REPORT

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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	2 February 2022	Meyer, Wolfgang

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ANNEX TO THE EUROPEAN SEARCH REPORT
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