Electronic Journal of University of Aden for Basic and Applied Sciences

EJUA-BA Vol. 2 No. 1 (2021)
https://doi.org/10.47372/ejua-ba.2021.1.84
ISSN: 2708-0684

RESEARCH ARTICLE

AUTODETECTION ALGORITHM OF PPG AND ECG PEAKS BASED ON 2 MOVING WINDOWS

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Received: 01 December 2020 / Accepted: 15 January 2021 / Published online: 31 March 2021

Abstract

In this study, an algorithm autodetection of PPG (Photoplethysmography) and ECG in an electrocardiogram is proposed. Many researches have been done for developing a new approach in this field, using different algorithms ranging from filtering and threshold methods, through wavelet methods, to neural networks, and others, each of which has different effectiveness and weaknesses. Although their performance in general good, but, the main weakness is that they are threshold dependent. Threshold-free detection is another proposed algorithm, where RR moving interval is calculated based on normal maximum and minimum heart rate (HR). This has the advantage of ensuring that every R-peak is contained between the edges of the moving interval. Thus, the effectiveness of this algorithm is that it is threshold independent, but its weaknesses are in the change in the RR interval according to the change in the heart rate frequency, which leads to missing some peaks. The effectiveness of the new algorithm autodetection peak is developed to overcome the weaknesses of threshold dependent and threshold independent algorithms. It based on a threshold-free algorithm with double moving windows. The complete algorithm is implemented using MATLAB 7.4. The method is validated using 18 recorded signals. The average sensitivity and average positive predictivity of PPG are 99.5% and 99.6% and of ECG are 99.3% and 99.4% respectively.

Keywords: Photoplethysmography (PPG), HR, Threshold dependent and threshold independent, double moving windows.

1- Introduction:

Heart rate (HR) monitoring is a key feature to measure the continuous heart rate variability. Many methods are used for detecting PPG peaks or R peaks, where these signals provide wealthy information on the heart rate and other abnormalities. Pulse oximeters are used in a number of situations to non-invasively measure the heart rate and blood oxygen level (SpO2) of patients [1]. The peak detection algorithms for Electrocardiogram (ECG) signals are well developed and widely available. Whereas; there are only a few publications that describe algorithms to detect features in pulse wave signals such as arterial pressure wave and photoplethysmographic (PPG) signals [2]. The peak detection algorithm of Mateo Aboy et.al [2] use multi stage complex processing and has the inherent disadvantage of using heart rate for fixing of cut off frequencies and interval decision logic. Another important algorithm applicable to pulse wave signals is that of Ernesto F Treo et.al [3]. But it is meant for only beat separation and interval measurement and can't be used for peak detection. Hangsik Shin et al proposed an adaptive threshold method for peak detection of PPG signals, which is based on the processing of minimum and maximum amplitudes of a signal along with time intervals [4]. This method has a limitation in that it cannot classify incident wave peak and reflected wave peak of PPG signal. Bistra Nenova proposed an automatic algorithm for detecting pulse waves which are based on a seven-rule decision logic. The algorithm is very lengthy and lots of computations are required and more over each rising edge has to be tested with a seven-rule decision logic [5]. Srinivas and L. Ram proposed an algorithm that combines the technique of moving average of valley-peak differences with an adaptive threshold filtering to detect the systolic peaks [6]. D. Campbell et.al proposed an algorithm wavelet transform, reverse biorthogonal (rbio1.5) mother wavelet [7]. Dae-Geun Jang et.al propose a simple and low complexity pulse peak detection algorithm using cascaded recursive digital filters and a slope sum function (SSF) with an adaptive thresholding scheme [8]. Argüello-Prada et al. proposed an algorithm for peak detection in low-amplitude PPG signals in real time [9].

In this paper, a new auto detection algorithm for PPG & ECG R peak is proposed based on normal maximum and minimum heart rate, using updated RR moving interval with 2 windows to overcome the weaknesses of threshold dependent and threshold independent algorithms. This algorithm is able to auto detect the peaks at different levels of threshold, without threshold value as amplitude or time interval which is the main goal in this work.

2- Algorithm Description:

This algorithm is developed based on the threshold-free algorithm [10] to detect PPG and ECG peaks and to solve the difficulty of missed peaks. PPG signal has two peaks, corresponding to 2 waves, systolic wave and dicrotic wave Fig. 1.

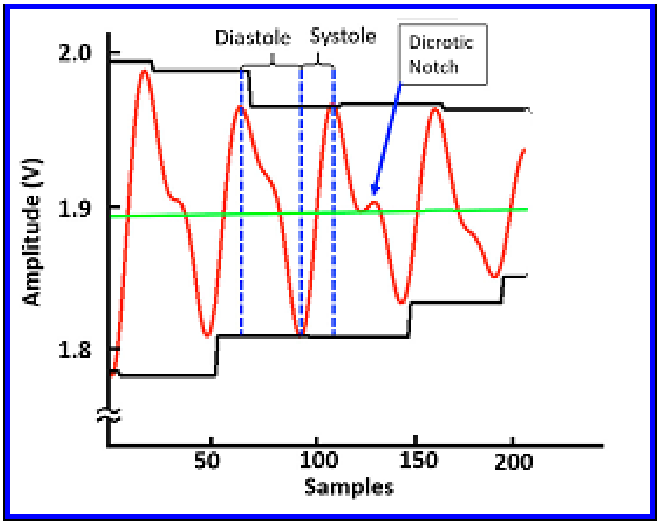

Fig. 1

Lines (1& 2) in Fig. 2, are passed in detected maximum ECG peaks and cross with them. These lines are passed very close to the minimum PPG peak, which is repeated in semi periodic manner (while these lines are passing between the indices of each 2 detected maximum PPG peaks vertically). All the indices of these peaks are detected nearly in the synchronization time, as shown in Fig. 2 (A& B).

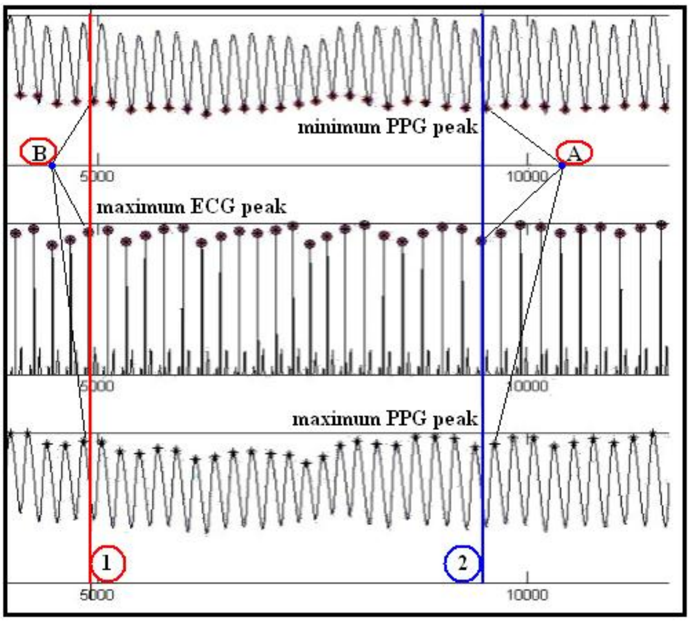

Fig. 2. Lines (1& 2) are crossed with R peaks and passed very close to min. PPG peaks

To evaluate PPG peaks detection, the ECG peaks are detected to be compared with the PPG peaks. Each PPG and ECG signals are recorded simultaneously from the same patient. Based on that, the minimum PPG peaks are the best to compare with ECG peak in detection for all PPG and ECG peaks Fig. 2.

I I. 1- Preprocessing:

A-DATA:

The method is validated using 18 recorded signals from the MIT-BIH arrhythmia database, which resembled 256 Hz. The recording time for each signal is about one minute.

B – Noise removal:

The undesirable high frequencies which do not contribute to the PPG peak detection are removed by using a band-pass filter 0.5-11 Hz, while other characteristic waves such as dicrotic wave as well as noises in the PPG signal are attenuated. After the recorded signal is fed to the filter, the output of the filtering stage will be fed to the next stage for peak detection. For ECG signals band pass filter 5-35 Hz and notch filter centered at 1 Hz are used to attenuate the baseline wander.

I I. 2- Peak detection:

This algorithm, auto detection for PPG and ECG peak is implemented based on the algorithm threshold free [9], threshold free algorithm has fixed moving widow repeats itself to detect Max (peak) as follow:

$$MP(i) = \max\left(Mi(i+17 : i+290)\right).i = 1 \qquad (1)$$

The newly developed algorithm auto threshold-free for PPG or ECG peak detection is implemented mainly on two windows, first window consists of three steps to enhance peak detection, and the second window to overcome the limitation of the changes in RR Intervals resulting from the change in the HR frequency.

The Principal of detection as shown in Fig.3 depends on each three peaks, each first peak (1) (last detected peak) must have a location smaller than the first edge of the moving window, the location of the third peak must have a location greater than the second edge and the second peak (2) should be in the range of the moving window.

Calculating RR is very important to definite the edges of the moving window, after detecting first peak MP (1) the window stars with first edge equal to the location of last detected peak (1) plus half RR interval (i+0.5*RR), and the location of second edge equal to the location of last detected peak (1) plus double RR interval minus 5 samples (i+2*RR - 5). Then this process will be updated automatically for detecting one peak only, peak (2) in every moving window (the moving window will be started after every detected peak (2) by 0.5*RR). Every detected peak (2) will be the first detected peak for the new updated moving window.

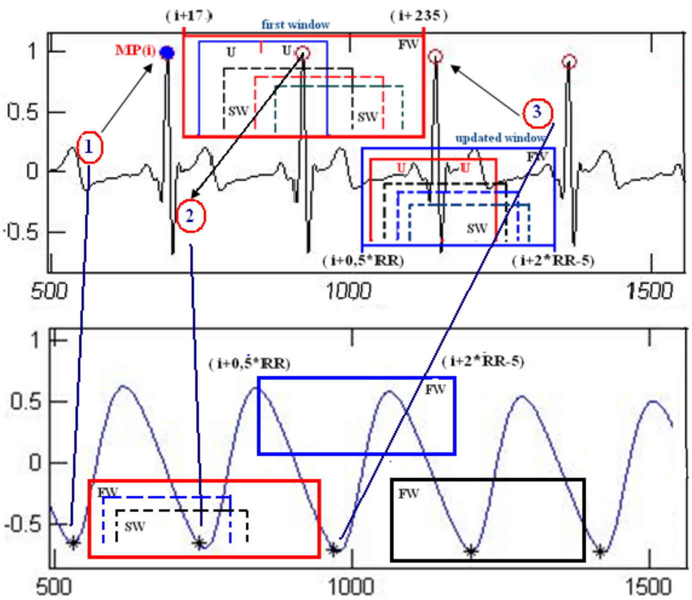

Fig. 3. Moving widows for peak detection

A: 1st window (FW):

Step: the first moving window (FW) is a moving window, designed to detect any peak in the range of (i+17: i+235) at the beginning of the signal only, which will fixed as first peak MP(i) = MP(1). After that the RR, 0.5*RR and 2*RR interval will be updated and calculated.

Step: after every iteration the first edge will start after the detected peak by (0.5*RR).

Step: the moving window will be updated, where (i + 0.5*RR) is the first edge and the second edge is (i+2*RR-5), then the range of moving window can be written as follow:

$$FW = (i + 0.5 \times RR : i + 2 \times RR - 5) \qquad (2)$$

B: 2sec window (SW):

The second window (SW) is a small window that moves inside each moving window (FW). It consists of 2 branches around its center each branch U = 80 samples as shown in fig(x).

$$SW = 2 \times U + 1 \qquad (3)$$

SW window searches for one maximum (or minimum) and compare it with other samples between each branches to correct any possible wrong peak detection as shown in Fig. 4 and Fig. 5.

3- Results And Discussion :

Table 1 summarizes how accurate the algorithm was in detecting peaks from PPG and ECG signals. An example of detected is shown in Fig. 4 PPG (a,b) and Fig. 5 ECG (c,d). As can be seen from these figures the proposed method successfully detected PPG and ECG peaks in these signals with a low SNR and prove the effect of the second moving window to correct the false negative detection Fig. 4 PPG (b) and Fig. 5 ECG (d).

Fig. 4. PPG detection

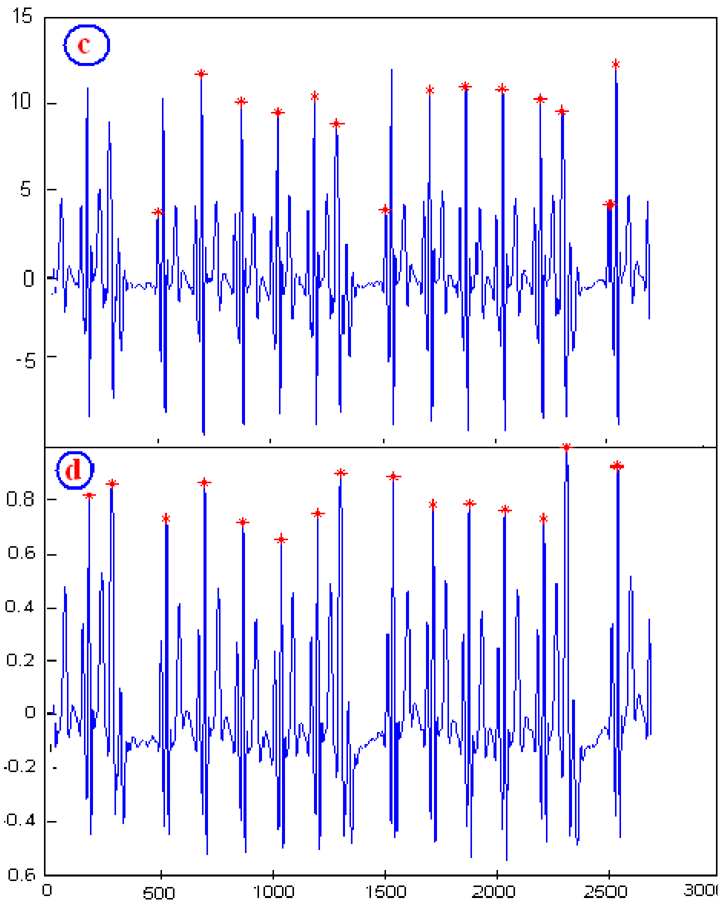

Fig. 5. ECG detection

To assess the performance, two statistical measurements were used [11]. The following statistical parameters were used to evaluate the algorithm: False Negative (FN): the peak has been missed. False positives (FP) represents the number of extra detections and true positives (TP) is the number of correctly detected. The sensitivity is the fraction of real events that are correctly detected and it is defined by:

$$Se = \frac{TP}{TP + FN} \quad (4)$$

The Positive predictivity is the fraction of detections that are real events and it is defined by:

$$+P = \frac{TP}{TP + FN} \quad (5)$$

Another statistical parameters are FDR used to evaluate the algorithm, where FN and FP counted as a detection of a detection error, so the failed detection rate FDR is defined by equation[6]:

$$\boldsymbol{FDR} = \frac{FP + FN}{TP} \quad (6)$$

The average Sensitivity (Se) of the algorithm for PPG and ECG are 99.5% and 99.3(%) respectively, and its Positive Predictiviti (+P) is 99.4 and 99.6(%) respectively. The FDR for detection of PPG and ECG are 0.9% and 1.12% respectively.

Table 1

sig.	ECG						PPG					
NO	TP	FN	FP	Se(%)	+P(%)	FDR(%)	TP	FN	FP	Se(%)	+P(%)	FDR(%)
1	66	0	0	100%	100%	0.0%	66	0	0	100%	100%	0.0%
2	60	0	0	100%	100%	0.0%	59	1	0	98.3%	100%	1.7%
3	92	1	2	98.9%	97.9%	3.3%	93	1	2	98.9%	97.9%	3.2%
4	77	0	0	100%	100%	0.0%	77	0	0	100%	100%	0.0%
5	74	1	2	98.7%	97.4%	4.1%	75	1	0	98.7%	100%	1.3%
6	74	0	0	100%	100%	0.0%	74	0	0	100%	100%	0.0%
7	66	1	0	98.5%	100%	1.5%	66	1	0	98.5%	100%	1.5%
8	86	0	0	100%	100%	0.0%	86	0	0	100%	100%	0.0%
9	69	1	0	98.6%	100%	1.4%	70	0	0	100%	100%	0.0%
10	81	1	0	98.8%	100%	1.2%	81	1	0	98.8%	100%	1.2%
11	68	0	0	100%	100%	0.0%	69	0	1	100%	98.6%	1.4%
12	83	1	2	98.8%	97.6%	3.6%	82	1	1	98.8%	98.8%	2.4%
13	62	0	1	100%	98.4%	1.6%	62	0	0	100%	100%	0.0%
14	80	0	0	100%	100%	0.0%	80	0	0	100%	100%	0.0%
15	79	1	0	98.8%	100%	1.3%	80	0	1	100%	98.8%	1.3%
16	72	1	0	98.6%	100%	1.4%	72	1	0	98.6%	100%	1.4%
17	72	0	1	100%	98.6%	1.4%	73	0	1	100%	98.6%	1.4%
18	68	1	0	98.6%	100%	1.5%	68	0	0	100%	100%	0.0%
Total				**99.3%**	**99.4%**	**1.2%**				**99.5%**	**99.6%**	**0.9%**

The algorithm shows its ability to detect signals with low noise and with the changes in heart rate (change in peak to peak interval) as shown in fig.(6). Most of the (FN) are due to the undetected first or last peak in these signals; these undetected peaks are not detected because there are not enough samples to create the second edge of the moving interval. An example of an undetected peak is shown in Fig. 7.

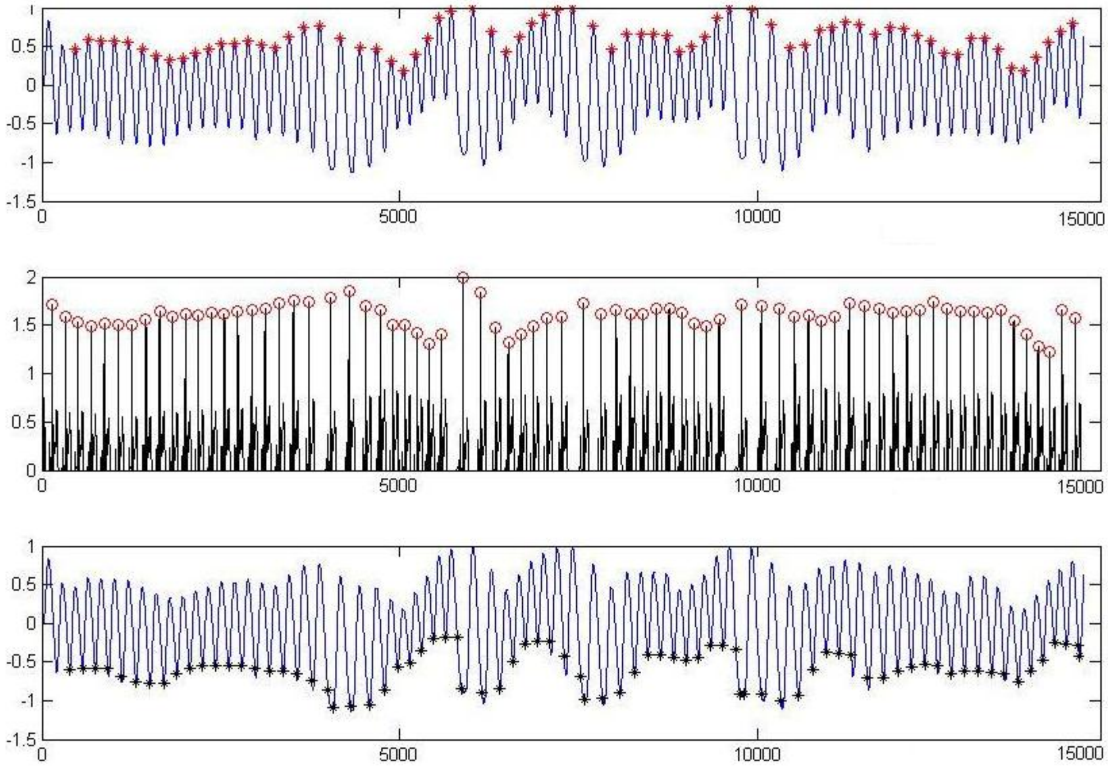

Fig. 6.

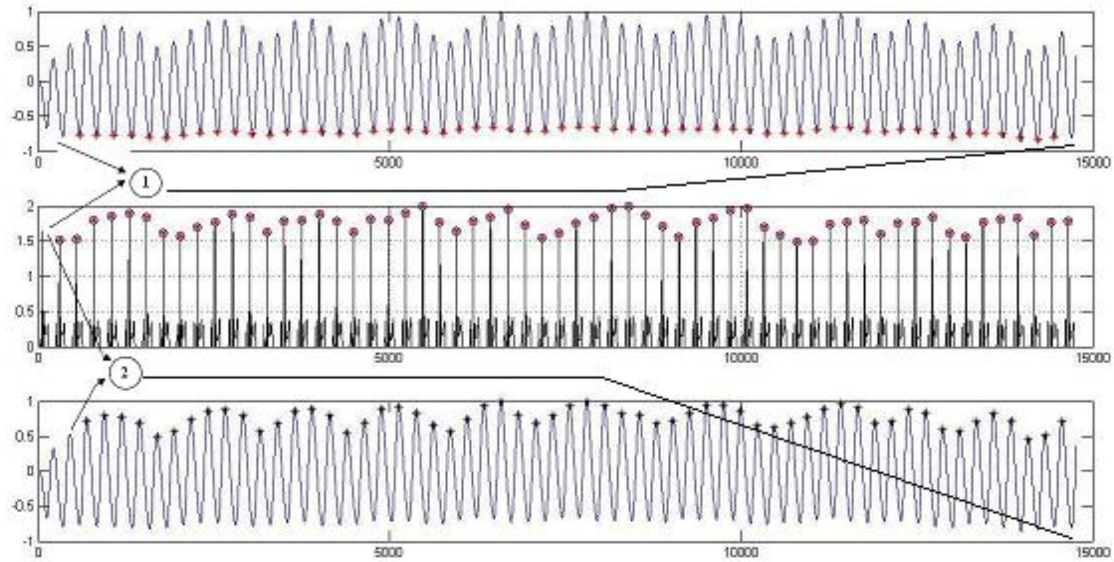

Fig. 7.

4- Conclusion

The Proposed algorithm is suitable for detecting PPG and ECG signals recorded simultaneously with different signal to noise ratio as described. The auto threshold-free detection algorithm has facilitated the detection of the PPG and ECG peaks automatically and without pre-determined thresholds. Minimum PPG peaks are the best to compare with ECG peak in detection for all PPG, due to the synchronization between the ECG R peaks and minimum PPG peaks Fig. 2. It is able to update the RR interval and the PPG peaks interval without the need for sampling frequency. The best advantage is that the FP (falls positive) will be the minimum rate for PPG and ECG (99.6% & 99.4%) respectively because it depends on updated interval only. The auto threshold-free detection algorithm has facilitated the detection of the PPG and ECG peaks and can be further enhanced to enable on line monitoring for T wave peaks detection, fetal peak detection, and PPG monitoring.

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مقالة بحثية

الكشف (الالتقاط) الاوتوماتيكي لقمم اشارة ال PPG واشارة القلب بناء على ثنائية نافذتين متحركتين

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استلم في: 01 ديسمبر 2020/ قبل في: 15 يناير 2021 / نشر في: 31 مارس 2021

المُلخّص

في هذه الدراسه تم وضع خوارزمية الالتقاط الاوتوماتيكي لقمم اشارة PPG التي يُمكن استِخدامَه للكشفِ عن تَغيرات حَجمِ الدمِ في طَبقةِ الأوعِيةِ الدَّمَويَّة معدل ضَربات القلب الى جانب اشارة القلب (ECG) باستخدام اشاره مسجله مكونه من اشارة PPG و ECG في نفس الزمن. هناك الكثير من الابحاث عملت لتطوير طرق جديدة في هذا المجال استخدم فيها خوارزميات مختلفة. تمتد من المرشحات الى طرق جهد العتبه مرورا بطرق الويفلت وطرق الشبكات العصبية وطرق اخرى وكل طريق لها مميزات فعالة ومميزات ضعف وبالرغم من ان اداء هذه الخوارزميات بشكل عام جيد الا انها تعتمد على جهد العتبة. ان طريقة جهد العتبة الحر ايضا هي خوارزمية قدمت حيث تم حساب مسافة RR الزمنية من خلال المدى الزمني المتحرك الذي يعتمد على أعلى واقل معدل تردد لضربات القلبٍ, وهذه الطريقه لها فائدة بان كل قمة موجة R تكون محتواه داخل هدا المدى الزمني المتحرك الى جانب تميزها بطريقة عتبة الجهد الحر. لكن ميزة ضعفها هي في تغير مسافة RR الزمنية وفقا لتردد ضربات القلب والذي يؤدي الى فقدان حساب بعض القمم. ان الخوارزمية الجديدة الالتقاط الاوتوماتيكي قد طورت لكي تتقلب موطن الضعف في تكنيك جهد العتبة وكذا جهد العتبة الحر. ان هذه الخوارزميه طورت على اساس جهد العتبة الحر ولكن مع استخدام ثنائية نافذتين متحركتين. ان هذه الخوارزميه بنية باستخدام التقنية البرمجية ماتلاب 7.4. كما تم تقييم وفحص هذه الطريقه باستخدام 18 سيجنال مسجلة. حيث كان معدل الحساسيه وكذا معدل التنبأ الايجابي لاشارة PPG بـ 99.5% و99.6% ولاشارة ECG بـ 99.3% و99.4% على التوالي.

الكلمات الرئيسية: تَغيرات حَجمِ الدمِ في طَبقةِ الأوعِيةِ الدَّمَويَّة، معدل ضَربات القلب، تكنيك جهد العتبة وكذا جهد العتبة الحر، ثنائية نافذتين متحركتين.

How to cite this article:

M. S. Mansoor, “AUTODETECTION ALGORITHM OF PPG AND ECG PEAKS BASED ON 2 MOVING WINDOWS”, *Electron. J. Univ. Aden Basic Appl. Sci.*, vol. 2, no. 1, pp. 07-13, Mar. 2021. DOI: 10.47372/ejua-ba.2021.1.84