Real Time Heart Rate Measurement and Heart Wave Drawing (ECG) Using Webcam

Yossra Hussain*, Ph.D. (Asst.Prof.) **Ahmed A. Shkara*, M.Sc.**

Abstract : Medically, the doctor uses his fingers to sense patient's heart pulse for measuring heart rate manually ,also he puts electrodes on patient's body to draw the heart wave (Electrocardiography (ECG or EKG)), and both processes are (contact based system). Medically, the heart pulse causes two invisible effects on human being, the first is a slight vibration in human head (motion) and the second is a slight change in skin color due to blood flow into skin (brightness). In this paper, an algorithm was developed to measure the heart rate and draw ECG diagram by webcam in real time without using any additional hardware (non-contact based system) and it can also be developed to help the doctors to examine their patients remotely via the Internet. The proposed algorithm use motion detection technique to detect the heartbeat from webcam frames, where the neighbors frames are subtract from each other to detect the head vibration and skin color change at that moment. The output of the subtraction is converted to a binary form and the sum of the resulting pixels represents the heartbeat values which are used to measure the heart rate and draw ECG. The traditional equation of heart rate calculate the heart pulse in one minute only, but the webcam may be opened for unknown time, therefore in this algorithm the Heart rate equation was developed to calculate the Heart rate in per second instead of per minute and for unlimited time (not only for one minute). The results show that, this algorithm able to measure heart rate with error rate not exceeding (2%) and draw ECG in real time using webcam and for unlimited time.

Keywords: Heart Wave drawing, Electrocardiography (ECG or EKG), Motion detection, Heartbeats detecting, Maxima Peaks detection, Face detecting, Head vibration.

* Computer Science Department, University of Technology, Baghdad , Iraq

1. Introduction

Measuring Heart rate and drawing Heart Wave (ECG) one of the most common procedures performed by doctors [1]. Using camera to measuring the heart rate and drawing Heart wave (ECG) is cheaper, faster and more comfortable than putting electrodes on patient body. Heartbeat and blood flow through the skin causing two invisible effects on humans. The first is a slight vibration in human head (motion), and the second slight change in skin color (brightness). Some research relies on human head vibration (motion) to detect the Heartbeat [2] and the other relies on skin color change to detect the Heartbeat [3]. In order to make the heartbeat detection from webcam become more robust, an algorithm was proposed to detect Heartbeat by combining between the two previous methods (head vibration and skin color change). The sequence of operations in this algorithm is. First, read the frames from webcam and use face detection technique to isolate the face area from the rest of the frame [4]. Second, subtract the face areas in neighbor's frames from each other to detect Heartbeat and drawing complete Heart Wave (ECG). Third, detect Heart pulse (Maxima peaks) from complete Heart Wave and calculate the time in second depending on webcam speed (not on computer time). Finally, Heart pulse number with the time that has been calculated is used to measure the Heart Rate. The results show that the proposed algorithm with face detection technique able to detect heartbeat and drawing Heart Wave (ECG) and measuring Heart rate.

2. Related Works

In 2012, H.Yu Wu [5], amplifies heartbeat depending on skin color change in human face. This method was applied on videos not on real-time.

In 2013, G. Balakrishnan[6], the heart rate is calculated depending on human head motion not on human skin color change. This method was applied on videos not on real-time.

In 2015, A. Lam [7], the heart rate is calculated depending on skin color change in human face. It use only green (G) channel to detect the brightness variations in face skin. This method was applied on videos not on real-time.

In 2015, M.Sushma[8], Motion Magnification and detection depending on time frequency analysis to large motion not on human skin color change. This method was applied on videos not on real-time.

In 2015, M. A. Elgharib [9], amplifies small movements within large ones depending on motion within interest area. This method was applied on videos not on real-time.

In 2016, H. Rahman[10], the heart rate calculated in real time depending on skin color change in human face not on human head motion. The method use webcam with face tracking to record 30 video frames, and then work off line to analyzing the frames for measuring heart rate. The problem here is that the patient in emergency needs to keep checking his heart rate continuously, not for 30 frames only.

In 2017, Y.Chen Lin [11], the heart rate calculated in real time using human head motion with additional hardware (near infrared (NIR) LEDs). The problem here is, using additional hardware makes the system more expensive and putting infrared LEDs on patient's head is uncomfortable for patients.

3. Proposed Work

Medically, the doctor uses his fingers to detect heart pulse and measuring heart rate. As it is shown in (B), the complete heart wave has many heart pulses (Maxima peaks) and only these peaks are used to measure heart rate.

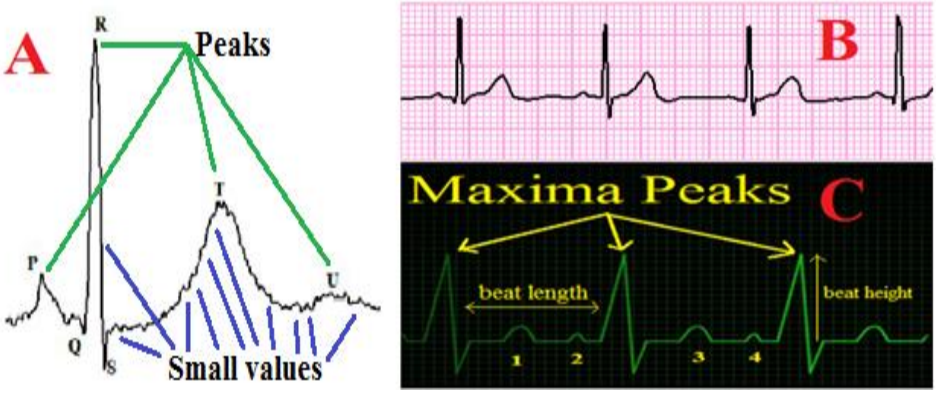

Figure (1): (A) Single heartbeat, **(B)** heart wave **(C)** The Pattern of heart wave.

As it is shown in (A), single heartbeat contains several peaks (r, R, t, and u), only Heart pulse (Maxima peak R) is used to measure heart rate ,and the rest of the smaller peaks (r, t, and u) are neglected because it cannot be detect by fingers when measuring the heart rate. As it is shown in (B), the complete heartbeat wave has many heart pulses (Maxima

peaks). As it is shown in (C) Heart pulses (Maxima peaks) have a pattern and the properties of that pattern as in flow:

- Heart pulses (Maxima peaks) appear almost at specific intervals of time.
- Heart pulses (Maxima peaks) higher than its four small neighboring peaks.

Note. Any wave doesn't have that pattern; either it is not a heart wave or an irregular heart wave (Heart disease).

3.1. Acquiring Heart Wave Values From Frames

Each frame contains a part of heart wave, and the sequences of frames represent the complete heart wave. So, to acquire all values of heart wave, neighbored frames are subtracted from each other (motion detection) and the result of subtraction convert to binary format and then sum the one's bits in it. Each sum represents a part of heart wave and all the sums values represent the complete heartbeat wave that extract from frames which will be used to measure heart rate and drawn ECG.

3.2. ECG Testing

In related works, it was noted that some research uses the Red color channel (R) to detect heart wave, assuming that the flow of blood to the face increases the redness of face skin. In other research, the Green channel (G) was used, assuming that the flow of blood to the face makes face skin darker. In this work, the frames was decomposed into its three colors (RGB) to search for heart wave pattern, and then Sine function is used to plot ECG. Each color was tested to see which of them are affected by heartbeat, and the results were as follows:

3.2.1. ECG Testing on Human Beings

All colors were affected by heartbeats, where the skin becomes more darkness and this change in skin color can be used to detect the heart wave. Figure (2) shows the heart wave pattern appear as ECG in all colors of frames. As it is shown, the Maxima peaks appear almost at specific intervals of time. For this reason, all colors were used in this work to detect the heartbeat.

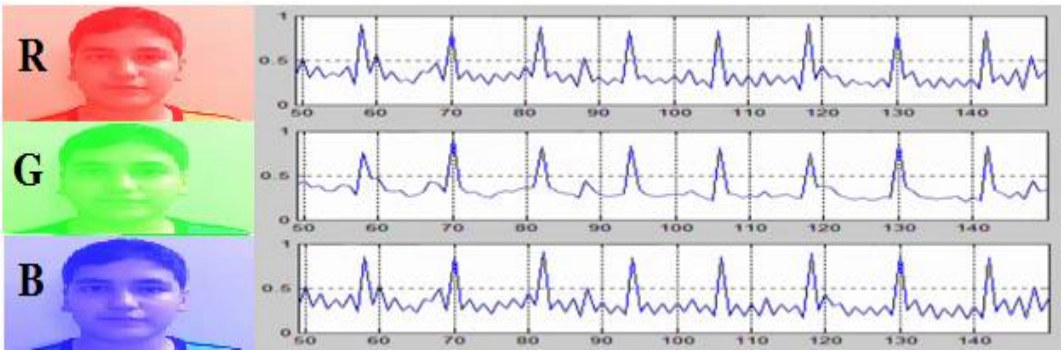

Figure (2): heart wave pattern appear as ECG in all colors of frames (RGB).

3.2.2. ECG Testing on White Noise

The “static white noise of color TV” was tested and the wave in figure (3) didn’t show ECG pattern of heart wave (No peaks - just a horizontal line).

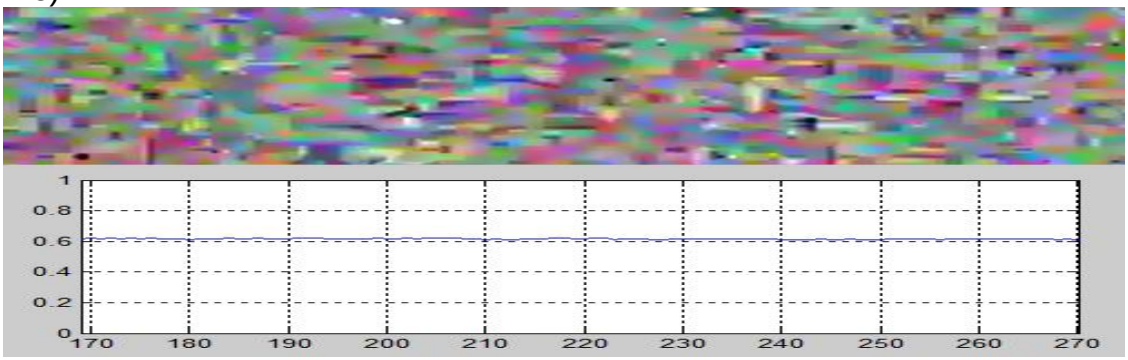

Figure (3): ECG testing on static white noise of color TV (No peaks)

3.2.3. ECG Testing on Object (Guitar):

Guitar with vibrating strings was tested as object. The vibrating strings make some peaks randomly, but it does not appearing at specific intervals of time as in a heat wave pattern. So it doesn’t heart wave, see figure (4). Moreover, even if the wave of guitar (or any object) appears as a heart wave, it does not considered as heart wave, because the guitar is not a human being.

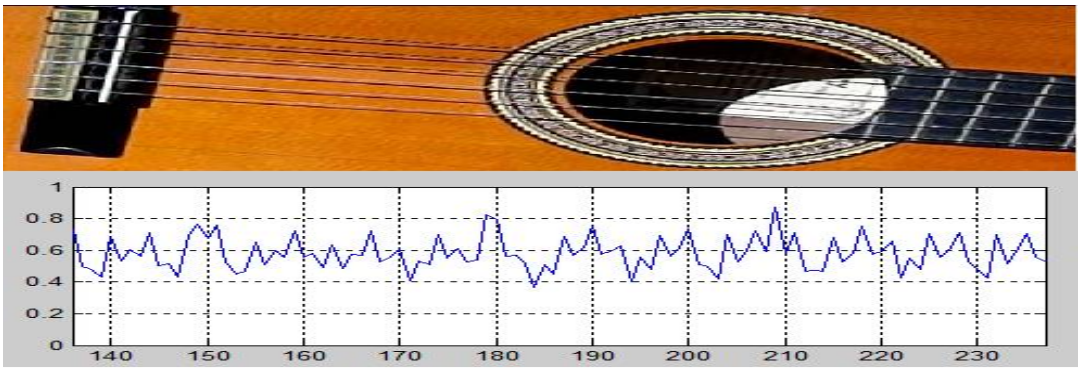

Figure (4): ECG testing on guitar with vibrating strings as object.

4. Proposed Algorithm

The proposed algorithm contains several operations. First, frames read sequentially from webcam in Interval: Discrete 0.133s (7.500 fps) resolutions (640 x 480) or (320x240), and then detect the face areas from each two neighbored frames. Second, acquire heartbeat value by subtract the neighbored face areas from each other , then convert the result to binary image and sum the one's bit in binary image. Third, Use sum values with Sine function to draw ECG Sequentially. Fourth, enter the sum values into queue from right to left then use slide window in the middle to detect heart pulses. Fifthly, calculate the time for one second depending on the speed of the webcam (not on the real time of the computer). Finally, use the time with the number of heart pulses to measuring the heart rate.

Algorithm : Real Time Heart Rate Measurement and ECG Drawing Using Webcam
Input : Video
// Vector use as slide window to detect pulse *//*
Queue [5] = All 5 element is zero
Pulse = 0 , Heart_Rate =0 , Time = 0 , Frame_No = 1
Output: Heart Rate Measurement AND ECG drawing

*// * Webcam Resolutions (640 x 480) or (320x240)*//*
Step 1. Read Current_Frame from Webcam
Step 2. While (Webcam Not Stop) Do *//* Event loop *//*
If (Face Detection in Current_Frame = true) Then
Face_area1= Face Detection from Current_Frame
// Which loaded in step 1 * //*
// the coordinate of face area 1 is Top left point= (x1, y1) and Bottom down point= (x2, y2) * //*

Calculate the coordinate of Face area1 in Current_Frame
Read Next_Frame from Webcam
// Increase the number of input frames *//*
Frame_No = Frame_No +1
Face_area 2 = Detect Face from Next_Frame using the coordinate of Face area1

//*===Detect Heartbeat values ==*//

*//*1- Subtract the neighbored frames from each other *//*

Step 3. Result_frame = ABS (Current_Frame - Next_Frame)

*//*2- Binaries the Result_frame*//*

B_frame =Convert to Binary (Result_frame)

// Binary frame (B_frame) it just two dimension array contain two values 0 and 1 *//*

*//*3- Calculate the **Sum** of one's bits in binary fame (B_frame) *//*

[Row, Column]= size of (B_frame)
Sum = 0
For I=1 to Row
For J= 1 to Column
Sum = Sum + B_frame[I , J]
End For J , I

*//*4- Enter the Sum value from the right of the Queue *//*

Queue (5)=**Sum** *//* Sum it just one value from complete Heart Wave *//*

// ECG drawing *//*

Step 4. Draw ECG using **Sum** value with **Sine** function

// Heart pulse detection *//*

Step 5. if (Queue (3) > Queue (1) AND Queue (3) > Queue (2) AND Queue (3) > Queue (4) AND Queue (3) > Queue (5))
Pulse = Pulse +1 *// * The Number of Heartbeat over the time *//*
end if

*//*Shift all Queue elements to left (Slide window) *//*

Step 6. For X =2 to 5
Queue (X-1) = Queue (X)
End for

// Calculate one second of a time depending on webcam speed (usually 7 frame in a second) .. webcam speed Interval: Discrete 0.133s (7.500 fps)*//*

Step 7. If (MOD (Frame_No , 7) = 0)
Time = Time +1 //* Time calculation*//

// Heartbeat Rate Measurement in per second *//*

Step 8. Heart_Rate = (Pulse * 60) / Time
End if
Else *//* Else of if Face Detection in Current_Frame *//*
Sum = 0;
End if *//*End of Face Detection in Current_Frame *//*

// Output the results *//*
Step 9. Output (Current_Frame + Face Detection , **Heart_Rate**)
// Swap the frames *//*
Step 10. Current_Frame = Next_Frame
End While *//* End of Step 2 *//*

4.1. Face Detection Technique

After reading the frame from webcam, face detection technique is used to isolate the face from the background and then the heartbeat is detected only from the face area, see in figure (5). As a kind of protection to this algorithm, the process of facial detection control on all steps of algorithm. In other words, when the face is detect, the process of heartbeat detection, ECG drawing and heart rate measurement will be continue .Otherwise all these processes will be suspend until the face is detect again.

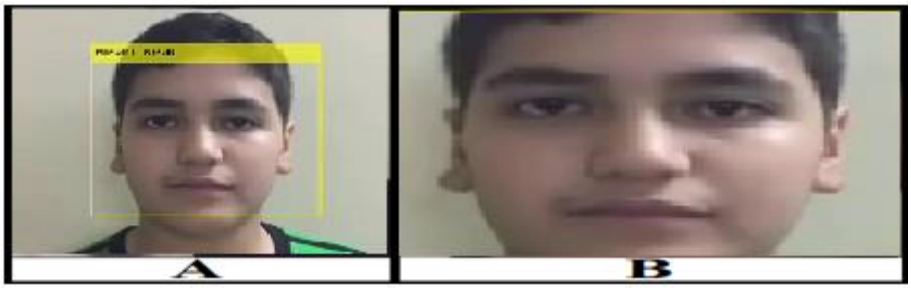

Figure (5): (a) face detection, (b) face area

As it is show in figure (1), the process of face detection may cut parts from background and clothing. These parts does not affect on the results because the color values of the background and clothing are fixed (do not changed) and will be deleted in the next step when subtracting face areas in neighbored frames from each other. Note that, to subtract two face areas, the two areas should be in same size and in same locations (coordinate). But the problem here is the size and locations of face area in current frame may be different from the size and locations of face area in next frame. This problem was solved here by calculate the size and location to face area in current frame and used to detect face area from next frame. Where the neighbored two face areas will be in same size and same location (fixed background). When subtracting neighbored face areas in the same size from each other, the skin color change will be detect and the backgrounds at the same locations (coordinate) is

necessary to detect head vibration. In next loop, the next frame will be the current frame and face detection will applied on it and the size and location of face area will be calculated depending on it and so on.

4.2. Detect Heartbeat Values

One heartbeat causes two effects on a human as in below:

A- Small vibration in head (movement- motion**).**

B- Small changes in pixels that represent the color of the skin (brightness).

To detect the previous effects and extract full heartbeat wave values, neighbored frames are subtracted from each other. The Pixel value of subtraction may be negative, so absolute function (ABS) is used to convert it to positive. In the resulting frame, some pixels will be removed and others will be remaining as in follow:

I. The Removed pixels.

Fixed background and skin pixels which have no color changes over the time will be removed.

II. The Remaining pixels (heartbeat wave).

The pixels of head motion (movement) and the pixels of skin whose color changes over time due to effect of blood flow in to skin (skin brightness) are remained, see figure (6).

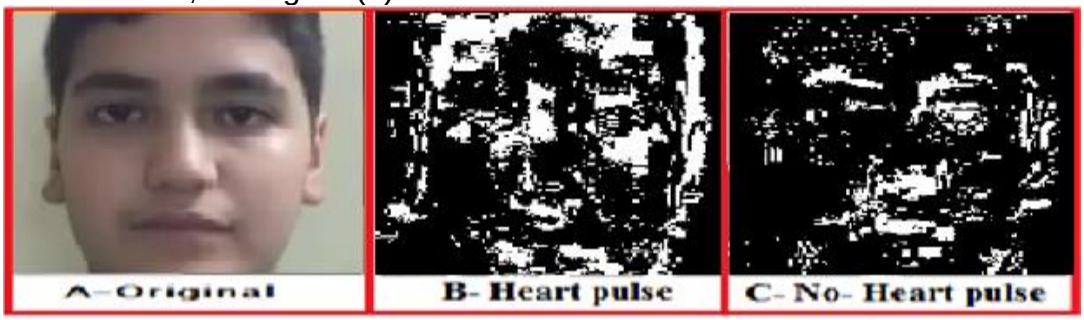

Figure (6): (A) face area, (B) heart beat, and (C) No heart beat.

.

As it is shown figures (A, B and C), the amount of pixels in figure B (heart beat) is more than the amount of pixels in figure C (No heart beat). In this algorithm, Heartbeat is detected by calculate the difference in pixels amount between frames. As it is show in algorithm, the results of subtraction for each two neighbored frames are converting to binary format and sum the one's bits in it. Each sum value represents one value from complete heart Wave.

4.3. Head Wave Drawing (ECG)

As in algorithm, the **sum** value with **sine** operation is used to drawing Heart Wave (ECG) in a sequential manner as in figure (7).

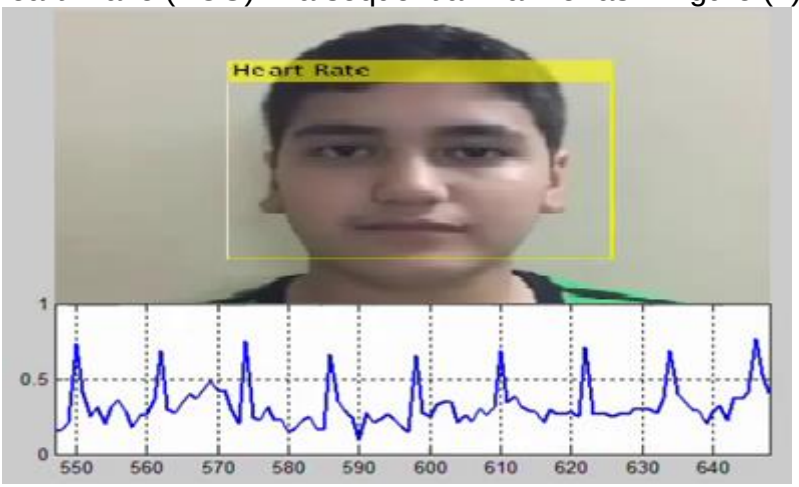

Figure (7): Heart Wave drawing (ECG)

4.4. Heart Pulse Detecting (Maxima peaks)

As explained earlier, Heart pulse (Maxima peak) has value larger than its four small neighbored peaks. So to detect Heart pulse from complete Heart Wave, a queue contains initially five zeros is used, after that the sum values entered into a queue from right to left (shift to left). Then middle slide window technique is used to check the value entered in the middle, If that value larger than its four neighbors values (small peaks), that is mean it is heart pulse value (Maxima peaks), Table (1) as example.

Table (1): Using Queue to detect Heart pulse from complete Heart Wave.

Round No. ←	1	2	**3 Middle slide window**	4	5
Round 1	0	0	0	0	0
Round 2	0	0	0	0	70
Round 3	0	0	0	70	80
Round 4	0	0	70	80	1000
Round 5	0	70	80	1000	50
Round 6	70 <	80 <	1000	> 50	> 40
Round 7	80	1000	50	40	900

4.5. Heart Rate Measurement.

Medically, heart rate is the number Heart pulse (Maxima peaks) in one minute. In This algorithm the heart rate is measured in per second (not in minute) for unlimited time (not only for one minute), as in the equations below:

Heart_rate = Sum of heart pulse in **one minute** (1)

As we know, One minute = 60 second .So to measure the heartbeat in a **second** (one minute):

Heart rate **=** Sum of heart pulse **in one second * 60** (2)

In order to measure the average of heart rate for two-second:

Heart rate **= (**Sum of heart pulse **in two - seconds * 60) /2** (3)

So to measure the heart rate for unlimited time:

Heartbeat rate **= (**Sum of heartbeat **in N - seconds * 60) /Time** (4)

In MATLAB the speed of webcam is (Interval: Discrete 0.133s (7.500 fps)). but computer speed defer from device to other, therefore the time in previous equation do not taken from computer timer, it calculated depending on webcam speed (about 7 frame per second) with the number of current frame using Modulo (MOD) operation between them.

5. Experimental Results

In this work, the algorithm has been programmed using MATLAB 2014, the program was implemented on a number of persons, The Heart Rate was measured (in per second), Heart Wave(ECG) was drawn and the results were compared with a medical device. Below, the results of three persons compared with a medical device.

5.1. First Person Test Results

As it is show in figure(8),the results are :

Time in seconds (S): Video in the second 62.

In this work, the heart rate was detected in per second. The reading of heart rate begins stability after 30 seconds and the final reading is approximately after one minute (60) seconds.

Measuring Heart Rate (R) from Algorithm: The Heart rate is 86.

Measuring Heart Rate from Medical device: The Heart rate is 84.

Medically, the the ranges of natural human Heartbeat Rate from 60 to 100,it depending on human age , health and his current state (A strained or not).

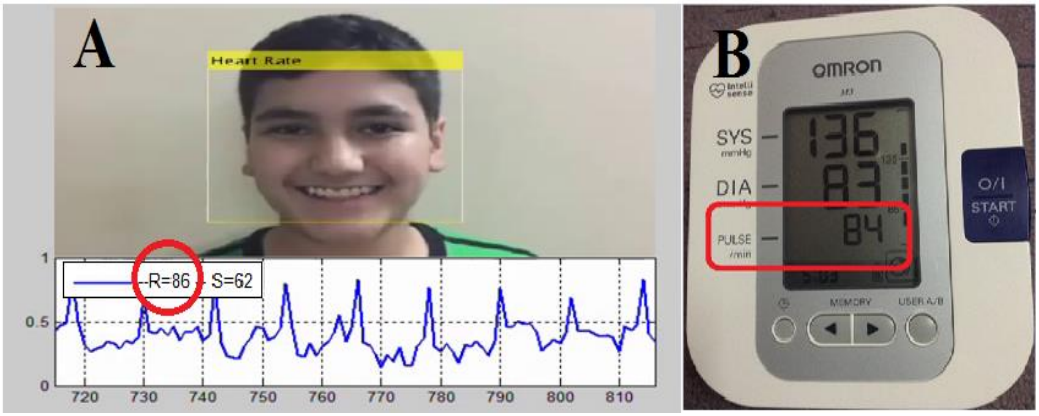

Figure (8): Heart Rate for first person from, (A) Algorithm, (B) Medical device.

5.2. Second Person Test Results

As it is show in figure(9),the results are :

Time in seconds (S): Video in the second 40.

Measuring Heart Rate (R) from Algorithm: The Heart rate is 89 .

Measuring Heart Rate from Medical device: The Heart rate is 89 .

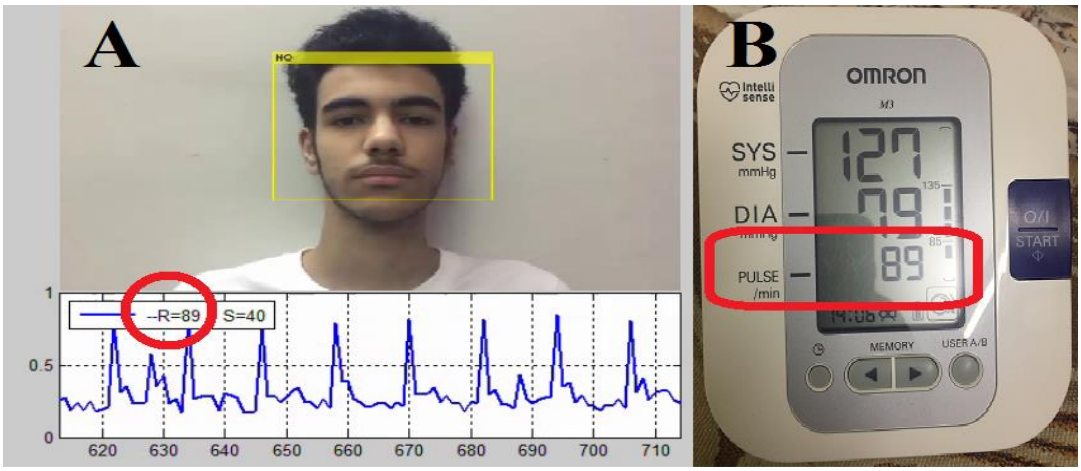

Figure (9): Heart Rate for second person from, (A) Algorithm, (B) Medical device.

5.3. Third Person Test Results

As it is show in figure(10),the results are :

Time in seconds (S): Video in the second 26.

Measuring Heart Rate (R) from Algorithm: The Heart rate is 76 .

Measuring Heart Rate from Medical device: The Heart rate is 77 .

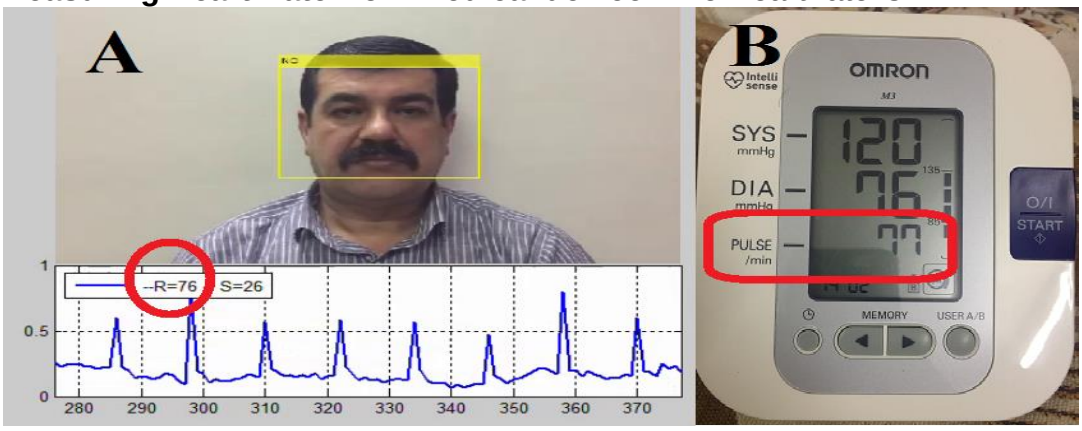

Figure (10): Heart Rate for third person from, (A) Algorithm, (B) Medical device.

5.4. The Efficiency of Algorithm

In order to test the efficiency of the algorithm, the measuring of Heart Rate from algorithm was compared with the measuring of heart Rate from medical device as in table(2).

Table (2): The efficiency of the algorithm

Test results to	Heart Rate from Algorithm	Heart Rate from Medical device
First person	86	84
Second person	89	89
Third person	76	77

By comparing table(2) values ,it has been found that comparing error rate does not exceed 2% .As explained above, Heart rate is within a wide range where it is between 60 and 100 pulse per minute, so losing one or even four pulses do not affect on heart rate measuring, so the efficiency of this algorithm is very good.

6. Conclusion

To detect heartbeat, some research depends on method use skin color change (brightness) and others depend on method use human head vibration (movement). In proposed algorithm, motion detection technique was used (by subtracting the neighbors frames from each other) to detect both skin color change and human head vibration at the same time. Combining between both previous methods (head vibration and skin color change) helps to detect the heartbeat even if the resolution of webcam is low. In this way, heartbeat detection was improved without using additional hardware. In this algorithm the heart rate was measured and the ECG was drawn for unlimited time depending on the time period in which the webcam was opened. As it is shown in results, the heartbeat was detected from webcam without using any additional hardware, the ECG was drawn and the heart rate was measured in real time for an undetermined time depending on the time period in which the webcam was opened. This algorithm can be developed to work on lie detector programs that are based on the principle of heartbeat detection.

References

[1]. R.Stricker, S. M¨uller, H.Michael Gross,"Non-contact Video-based Pulse Rate Measurement on a Mobile Service Robot ",Proc. 23rd IEEE Int. Symposium on Robot and Human Interactive Communication (RO-MAN 2014), pp. 1056-1062, IEEE , Edinburgh, UK , 2014.

[2]. K. Kamble, N. Jagtap, A. Bhurane, "A Review: Eulerian Video Motion Magnification ", International Innovative Research in Computer and Communication Engineering (IJIRCCE), Vol. 3, Issue 3, PP. 2-6, March, 2015.

[3]. M. Haque, K. Nasrollahi, T. Moeslund, "Heartbeat Signal from Facial Video for Biometric Recognition", 19th Scandinavian Conference in Image Analysis (SCIA),Vol 8127, DOI:10.1007/978-3-319-19665-7_14,pp 165-174, June 2015.

[4]. V.Gupta,D.Sharma."A Study of Various Face Detection Methods",International Journal of Advanced Research in Computer and Communication Engineering,Vol. 3, Issue 5, May 2014.

[5]. H. Yu Wu , M. Rubinstein, S. Eugene, T. Freeman, "Eulerian Video Magnification for Revealing Subtle Changes in the World", Quanta Research Cambridge, MIT CSAIL, Vol 31 , Issue 4,No. 65 ,July ,2012.

[6]. G. Balakrishnan, F. Durand, J. Guttag MIT CSAIL "Detecting Pulse from Head Motions in Video " , Paper provided by the Computer Vision Foundation ,available in IEEE Xplore,CVPR2013 ,2013.

[7]. A. Lam , Y, Kuno," Robust Heart Rate Measurement from Video Using Select Random Patches " , IEEE International Conference on Computer Vision, ICCV 2015, Santiago, Chile, ISBN 978-1-4673-8391-2, PP. 3640-3648. IEEE Computer Society,December 7-13, 2015.

[8]. M. Sushma ,"Time Frequency Analysis for Motion Magnification and Detection" M.Sc. Thesis, Electronics and Communication Engineering ,International Institute of Information Technology, Hyderabad, INDIA, May , 2015.

[9]. M. Elgharib, M. Hefeeda, T. Freeman, "Video Magnification in Presence of Large Motions", Computer Vision Foundation (CVF), IEEE Xplore , 2015.

[10]. H. Rahman, M.U. Ahmed, S. Begum, P. Funk, "Real Time Heart Rate Monitoring From Facial RGB Color Video Using Webcam", The 29th Annual Workshop of the Swedish Artificial Intelligence Society (SAIS). 2–3 June, Malmo, Sweden, 2016.

[11]. Y.Chen Lin , N.Kuan Chou , G.You Lin , M.Han Li and Y.Hsiang Lin,"A Real-Time Contactless Pulse Rate and Motion Status Monitoring System

Based on Complexion Tracking ",Sensors (ISSN 1424-8220; CODEN: SENSC9) Open Access Journal, Sensors published by MDPI,24 June 2017.

قياس معدل ضربات القلب في الوقت الحقيقي ورسم موجة القلب (ECG) باستخدام كاميرا الويب

أ. م. د. يسرى حسين علي* م .م. احمد عبدالله شكاره*

المستخلص: طبياً يستخدم الطبيب أصابعه لاستشعار نبض قلب المريض لقياس معدل ضربات القلب يدويًا، كما يقوم بوضع أقطاب كهربائية على جسم المريض لرسم موجة القلب (تخطيط القلب الكهربائي (ECG أو EKG) ، وكلا العمليتين هما (نظام قائم على التلامس). طبياً ، يتسبب نبض القلب في تأثيرين غير مرئيين على الإنسان ، الأول هو اهتزاز طفيف في رأس الإنسان (الحركة) والثاني هو تغير طفيف في لون الجلد بسبب تدفق الدم إلى الجلد (السطوع). في هذا البحث ، تم تطوير خوارزمية لقياس معدل ضربات القلب ورسم مخطط ECG بواسطة كاميرا الويب في الوقت الفعلي دون استخدام أي أجهزة إضافية (نظام غير قائم على الاتصال) ويمكن أيضًا تطويرها لمساعدة الأطباء على فحص مرضاهم عن بعد عبر الأنترنيت. تستخدم الخوارزمية المقترحة تقنية اكتشاف الحركة لاكتشاف ضربات القلب من إطارات كاميرا الويب ، حيث يتم طرح الإطارات المجاورة من بعضها البعض لاكتشاف اهتزاز الرأس وتغير لون الجلد في تلك اللحظة. يتم تحويل ناتج الطرح إلى نموذج ثنائي ويمثل مجموع وحدات البكسل الناتجة قيم نبضات القلب التي تُستخدم لقياس معدل ضربات القلب ورسم مخطط كهربية القلب. تحسب المعادلة التقليدية لمعدل ضربات القلب نبض القلب في دقيقة واحدة فقط ، ولكن قد يتم فتح كاميرا الويب لوقت غير معروف ، لذلك في هذه الخوارزمية تم تطوير معادلة معدل ضربات القلب لحساب معدل ضربات القلب بالثانية بدلاً من الدقيقة ولغير محدود الوقت (ليس فقط لدقيقة واحدة). أظهرت النتائج أن هذه الخوارزمية قادرة على قياس معدل ضربات القلب بمعدل خطأ لا يتجاوز (2٪) ورسم تخطيط القلب في الوقت الحقيقي باستخدام كاميرا الويب ولفترة غير محدودة.

الكلمات المفتاحية: رسم الموجة القلبية، تخطيط القلب الكهربائي (ECG أو EKG)، كشف الحركة، كشف دقات القلب، كشف القمم القصوى، كشف الوجه، اهتزاز الرأس.

* قسم علوم الحاسوب، الجامعة التكنولوجية، بغداد، العراق.