Improved Algorithm for Heart Rate Measurement Using Mobile Phone Camera

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Abstract

Nowadays a lot of different ways to measure person's heart rate are exist. One of such ways is using mobile phone. It is very easy for the person and do not require any special skills or buying special devices. All that is needed for heart rate measurement is mobile phone with on-board camera with flash equipped.

In this paper we overview existing algorithms for heart rate measuring using mobile phone and propose improved algorithm, that is more efficient, than reviewed ones.

Index Terms: mHealth, Pulse detection, Heart rate, Mobile phone, Camera.

I. Introduction

Heart rate is a number of human heart beats per unit of time. Typically it is expressed as beats per minute (bpm). Heart rate helps to detect such diseases as tachycardia and bradycardia. Heart rate monitoring during physical exercises allows to avoid health hazards and to estimate the extent of one's physical training [1].

The most usual way to measure heart rate is manual measuring. Nowadays special devices, such as electrocardiographs, heart rate monitors and pulse oximeters, are used to measure heart rate. Heart rate monitors are portable personal devices that allow to continuously measure person's heart rate. Currently, heart rate monitors have received a wide distribution, especially among sportsmen, because they allow to monitor heart rate during physical exercises, when manual measuring is not possible [2].

Sometimes people need to know their heart rate, but they neither have an appropriate monitor nor know how to measure heart rate manually. In this case mobile phone can help them. Today there are mobile applications that allow to measure person's heart rate using the phone's camera. For the user measuring heart rate using mobile phone looks very simple. He or she starts the application, places one's finger over camera lens and presses a button. After that application turns on camera flash and starts the measurement. During the measurement application captures frames from the camera, analyzes them and then, after measurement done, shows the measured user's heart rate on the screen. Usually measurement takes 10 seconds.

There are several algorithms for heart rate measuring using mobile phone described in scientific literature. However, their performance was found not permissible for use in real applications. In this paper we propose an improved algorithm for heart rate measuring using mobile phone, which first version was described in [3], that is more efficient, than existing ones. It allows to calculate person's heart rate using data, gathered from mobile phone's camera.

The rest of the paper is organized as follows. In Section II we give detailed description of main idea of heart rate measuring using mobile phone. Section III contains overview of

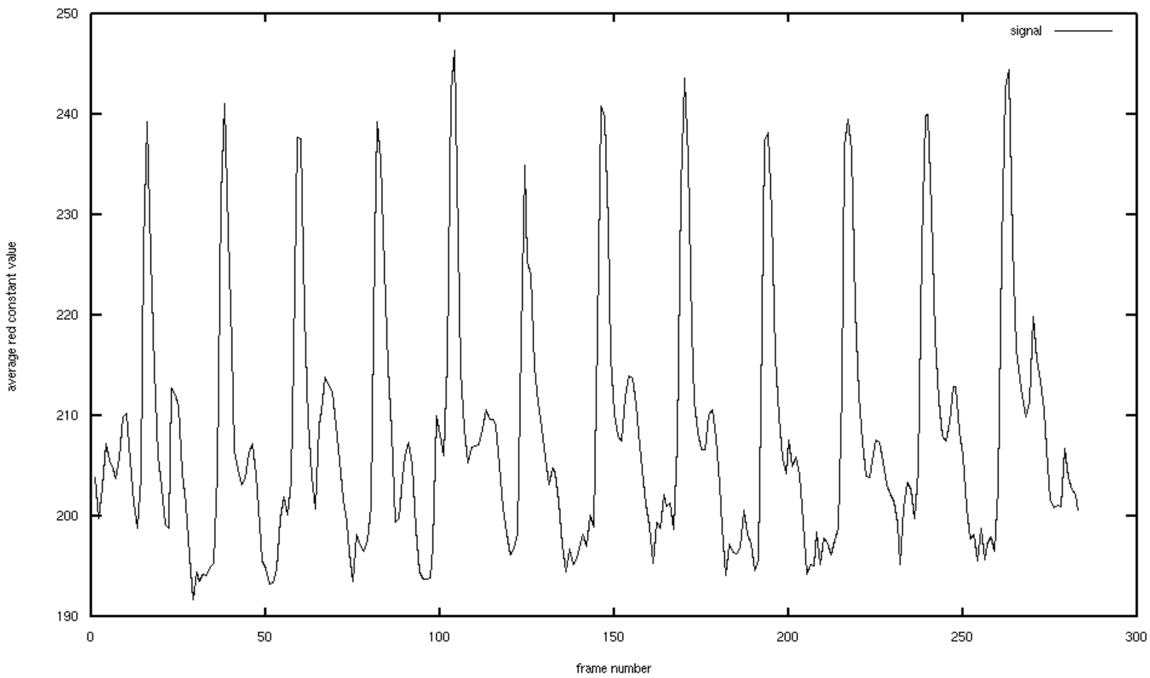


Fig. 1. Time series of average red component values of the frames

existing algorithms for heart rate measuring using mobile phone. In section IV we describe first version of the proposed algorithm [3], it's issues and improvements, that were made in it. Section V contains performance comparison of all considered in this paper algorithms. In conclusion we report about implementation of proposed algorithm in Pulse Detector application.

II. Main idea of heart rate measuring using mobile phone

The main idea of measuring heart rate using mobile phone is to detect variations in finger skin color and brightness that occur due to blood pulsation using on-board phone's camera. The detection is made by analyzing average red component values of the frames or part of the frames taken by the camera.

Time series of average red component values of the frames is considered as input signal for heart rate measuring. The example of such signal is shown in Fig. 1. The signal contains "sharp" local maxima called peaks. Each peak corresponds to a single heart beat. Number of heart beats and length of the measurement are all that is needed to calculate the heart rate.

Unfortunately, the original signal is too noisy and may contain fake peaks or data loss due to movements of the finger above camera lens and changes in surrounding light level during the measurement. That is why we cannot rely on number of raw signal peaks for heart rate calculation. We need to use algorithms that receive signal as input and give calculated heart rate on the output. In the next section we consider two of such algorithms.

III. Existing algorithms

We considered two papers describing how to measure heart rate using mobile phone's camera.

The algorithm described in [4] proposes to filter signal with a moving average filter. Then filtered signal is split into windows of fixed length and for each window the signal is compared

TABLE I
PERFORMANCE OF HEART RATE CALCULATION ALGORITMS

Algorithm	Incorrect calculations, %	Relative error, %
Moving average filter [4]	20	8.5
Smooth differentiation [5]	20	13.16
First version of proposed algorithm [3]	20	41.38
Current version of proposed algorithm	8	10.93

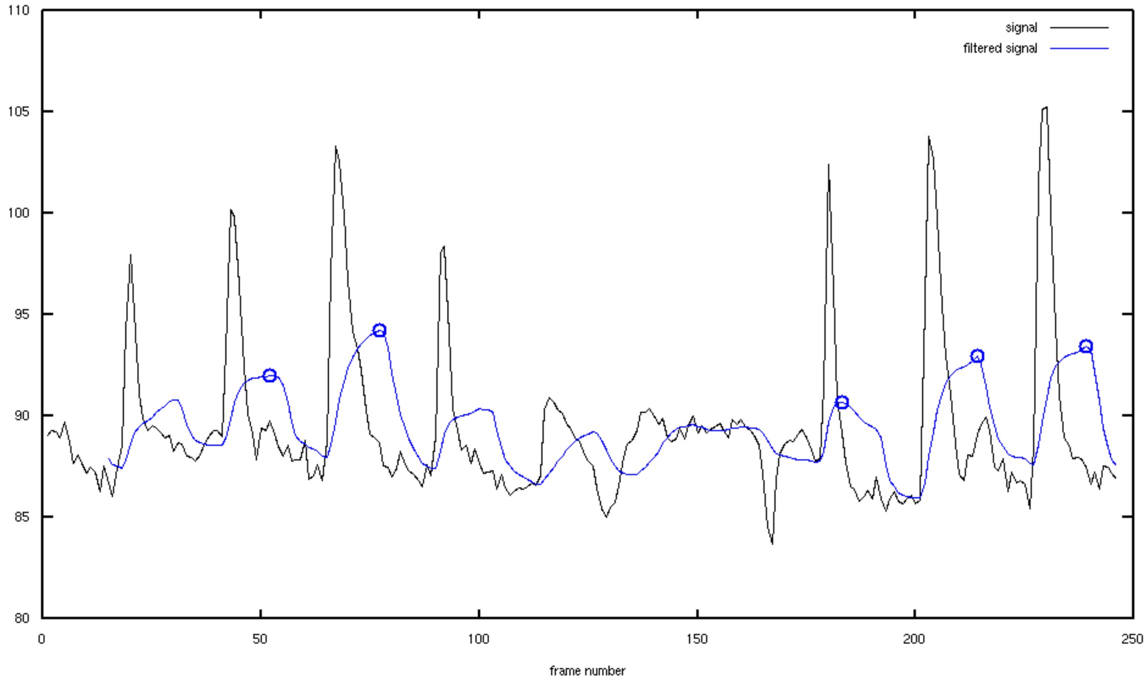


Fig. 2. Example of signal loss

to sinusoidal pattern. If the signal matches a pattern, the heart rate is calculated by determining the number of peaks and multiplying the peak count with the ratio of 60 to the window length.

In [5] authors propose to normalize signal using smooth differentiation. Then the number of peaks of the normalized signal is counted and divided by the length of the signal. The result of this operation multiplied with 60 is heart rate value.

To check both algorithms for possibility of use in real applications it is needed to estimate their performance. For this purpose we made a set of 50 test measurements. For each measurement a signal of average red component values of the frames was retrieved. Since there was not given any information about filtration parameters and peak detection in [4] and [5], we chose parameters that gave the least number of errors. For peak detection we used Octave script, developed by Eli Billauer: *http://www.billauer.co.il/peakdet.html*.

Results of performance estimation are shown in first and second rows of the table I. For both algorithms 20% of all calculations gave values that differ from real heart rate values for more than 5%. The reason of such bad results is inaccuracy of input signal. Filtration cannot deal with signal loss (Fig. 2 shows example of signal loss in the middle of the measurement) that exist in signal due to movements of the finger among the camera lens. Also filtration can smooth some real peaks (Fig. 3 shows two examples of how filtration smooths real peaks).

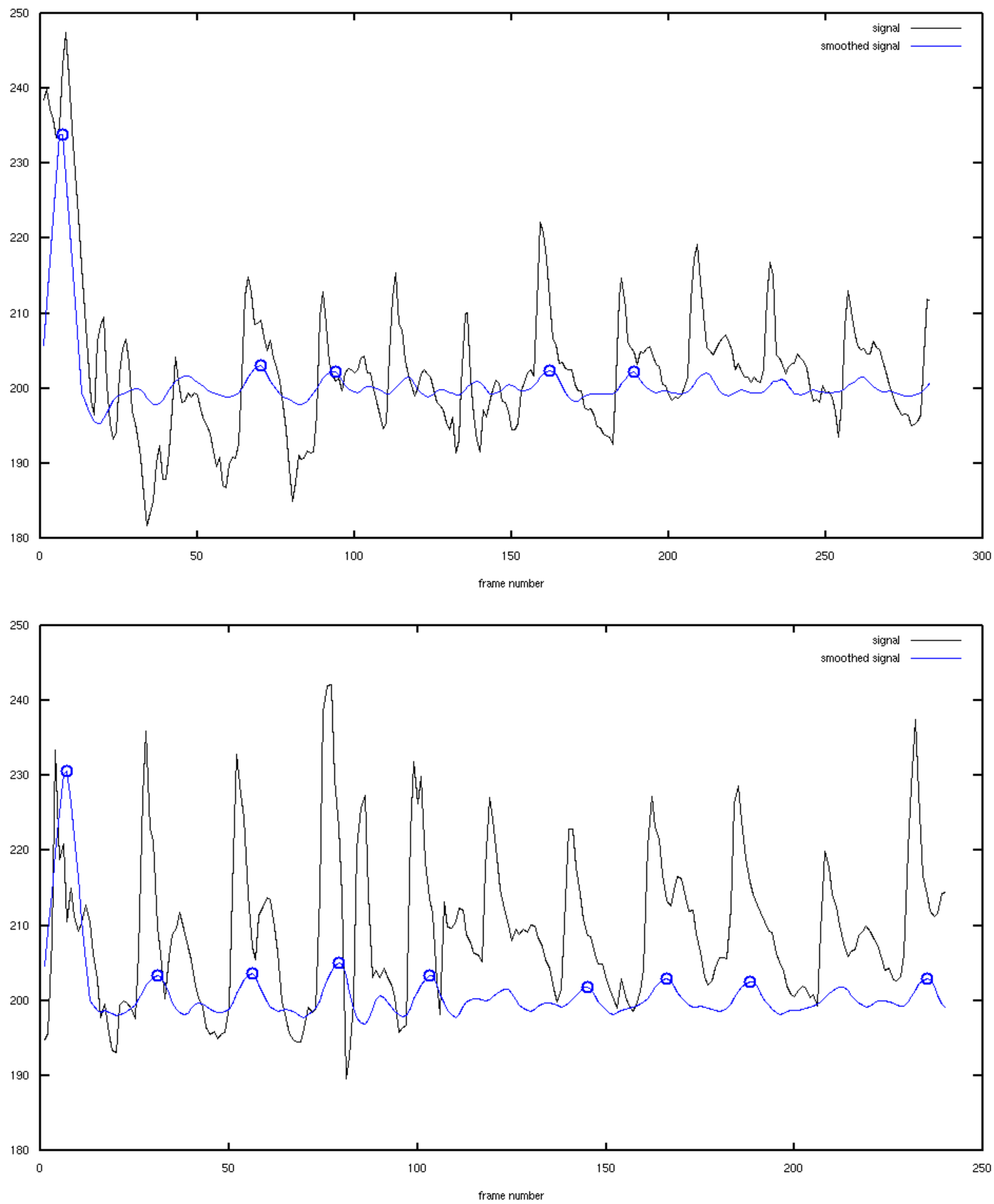


Fig. 3. Example of filtration smoothing real peaks

Such big percent of errors is impermissible for real applications that is why we decided to develop our own algorithm. Also the reasons of inappropriate performance of considered algorithms show that we cannot fully rely on filtration and we need another main idea for heart rate calculation.

IV. Proposed algorithm

The first version of the algorithm was described in [3]. The main idea of this algorithm is to calculate average distance between adjacent peaks.

The algorithm consists of following steps:

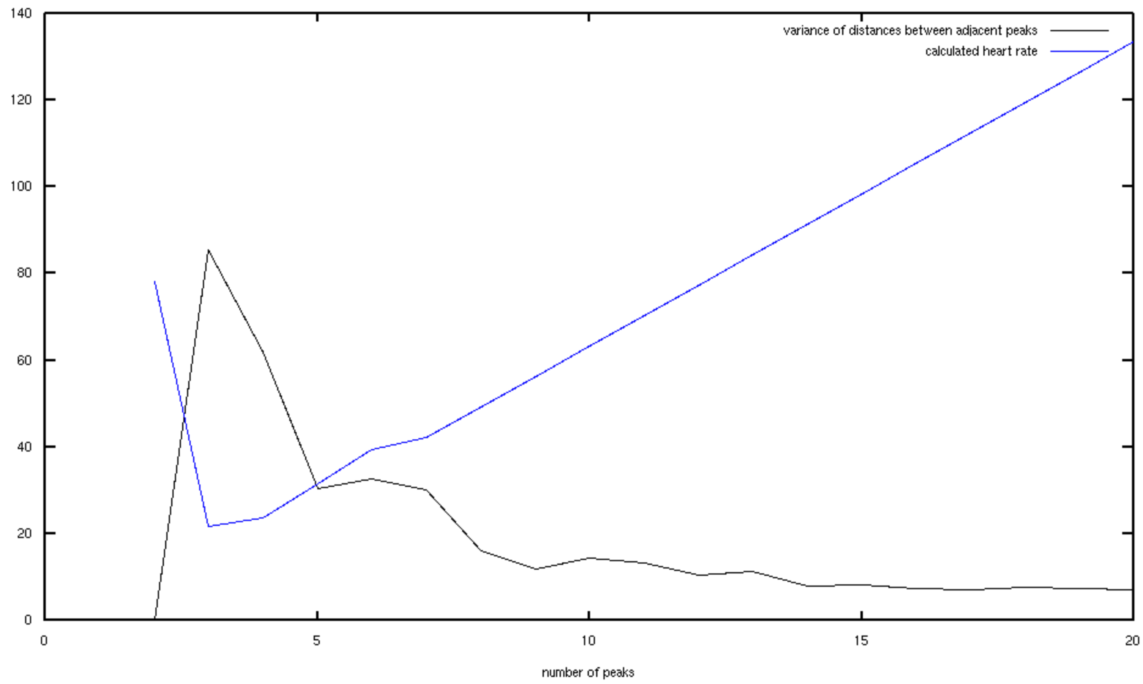
1) Signal differentiation. It allows to bring signal's average close to zero and to get rid of signal's baseline rising up or falling down that occur, when surrounding light level changes during capturing of the frames. So after differentiation we can easily compare hight of the peaks.
2) Collecting sets of k highest peaks of the signal. Here k changes from 3 to n, which is maximum number of observable peaks. For 10 seconds measurement we consider n equals 20.
3) Calculating variances of distances between adjacent peaks for each set of peaks collected on the previous step.
4) Choosing appropriate set of peaks. On this step we chose set of peaks, which variance value, calculated on the previous step, is minimum among other variances.
5) Heart rate calculation. We calculate mean value of distances between adjacent peaks for the set chosen on the previous step. Frame rate of the measurement multiplied by 60 and divided by this mean value gives heart rate in bpm for current measurement.

On the test data sets, that were collected to estimate performance of the algorithm, it showed good performance—approximately 10% of errors—that is suitable for personal non-medical applications. But after implementing first version of the algorithm in Pulse Detector application and releasing it, we received many responses indicated that application does not work good enough. We decided to collect more test data. On the collected test data set of 50 measurements first version of the algorithm showed 20% of errors that is shown in the third row of the table I. This result shows that performance of the first version of our algorithm is comparable by performance with algorithms considered in Section III. Therefore, the inital test data set was irrelevant.

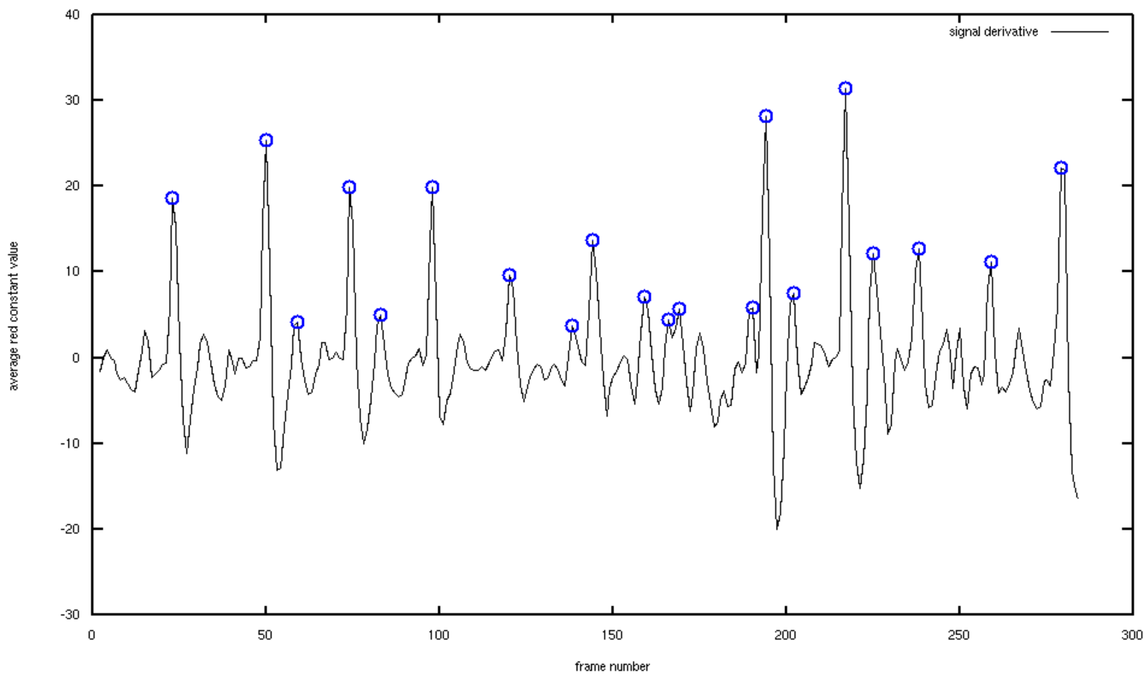
Looking into the reasons of such bad results showed that signal loss has no effect on the algorithm, but fake peaks and also signal noise sometimes lead to the situation, when minimum of the average distances between adjacent peaks is reached for the maximum number of observable peaks, while number of real peaks is less than this number. Example of such situation is shown in Fig. 4. This situation leads to incorrect calculation, where calculated heart rate is higher, than real one. This problem can be solved by decreasing maximum number of observable peaks, but it will lead to incorrect calculations for high heart rates, as they have more peaks in measurement. So this solution is not applicable.

To cope with this issue we introduce the following improvements to the algorithm:

1) Minimum number of highest peaks (k) from the 2nd step of the algorithm is increased from 3 to 5, because 5 peaks in 10 seconds measurement corresponds to heart rate of 30 bpm.
2) In the 4th step, if minimum variance value is reached for maximum number of peaks (n), then we chose set of peaks which variance value is first local minimum in the series of variances.
3) After choosing appropriate set, it is filtered by removing peaks that are distant from one of the adjacent peaks for less, than minimum permissible distance. The minimum permissible distance is equal to 60 multiplied by measurement frame rate and divided by 200. This distance corresponds to the heart rate of 200 bpm. The smaller distances



(a) Dependency between variance of the distances between adjacent peaks and calculated heart rate. Minimum variance is reached for maximum number of the peaks



(b) Signal derivative with selected peak set

Fig. 4. Example of algorithm error. Real heart rate: 77 bpm; calculated heart rate: 133 bpm

correspond to heart rates of more than 200 bpm, which are normally unreachable for human [6].

4) After previous step chosen set is filtered once more by removing peaks, whose distance to one of the adjacent peaks differs from the mean value of the distances between adjacent peaks of the set for more than *max_diff* percents. For our algorithm we consider *max_diff* value equaled to 25%.

The current version of the algorithm is presented below.

Algorithm 1 Heart rate calculation algorithm

Require: *signal* — time series of the average red component values of captured by camera frames; *frame_rate* — frame rate of captured data; *n* — maximum number of the peaks in the chosen set (default value equals 20); *max_diff* — maximum deviation of distances between peaks from their average value (default value equals 25%).

```
deriv = derivative of the signal
for value ∈ signal do
    if value == max of the value's 2-neighbourhood then
        peaks += value
    end if
end for
for k = 5 : n do
    distances = distances between adjacent peaks of k highest peaks from peaks
    variances += variance of the distances
end for
if min(variances) == n then
    chosen_set = set of distances that variance equals to first local minimum in variances
else
    chosen_set = set of distances that variance equals to min(variances)
end if
remove all values that are lower than frame_rate × 10/33 from chosen_set
repeat
    R = values of chosen_set that differ from mean(chosen_set) for more than max_diff
    remove R from chosen_set
until R ≠ ∅
heart_rate = 60 × frame_rate/mean(chosen_set)
return heart_rate
```

V. Performance of the proposed algorithm

First and current versions of the proposed algorithm, and also algorithms, described in section III were tested with testing data set of 50 measurements. Table I shows performance of proposed algorithm comparing to other algorithms.

For this comparison algorithm calculated heart rate values that differs from the real ones for more than 5%, were considered as incorrect. For algorithms described in [4] and [5] and also for the first version of proposed algorithm 20% of calculations were incorrect. For current version of proposed algorithm only 8% of calculations were incorrect.

Reasons of the errors of first two algorithms were considered in sections III. For the first version of the algorithm we described reasons of failures in section IV.

Analysis of the reasons of failures of the current version of proposed algorithm showed that there are situations, when the heart rate may change during the measurement. For example, in Fig. 5, calculating heart rate using average distance between three last peaks will give 109 bpm. And calculating heart rate using average distance between first peaks will give 72 bpm. The average heart rate for this measurement equals to 78 bpm. The heart rate calculated by current version of the proposed algorithm equals to 73 bpm, because algorithm consider last peaks as fake ones, as they are too close to each other. Such situations make up half of the incorrect calculations of the current version of the algorithm for the test data set. Another half of incorrect calculations appear because of very noisy signal, in which noise peaks are comparable to real ones.

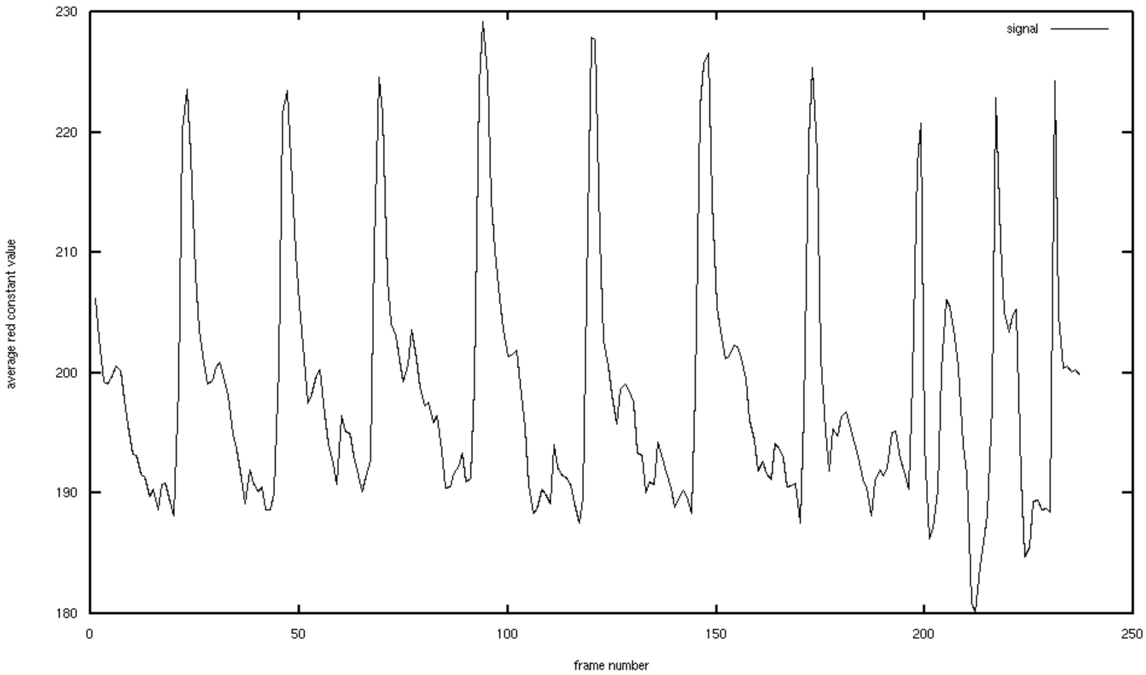


Fig. 5. Example of the situations, when the heart rate changes during the measurement

VI. Conclusion

In the paper we made a review of existing algorithms for heart rate measuring using mobile phone. It was found, that their performance is not permissible for use in real applications. So we proposed an algorithm, which main idea is different to reviewed ones. Performance of this algorithm was equal to performances of other algorithms. So we made an improvements in the proposed algorithm, which raised performance in more than two times. The algorithm is much more efficient, than the other algorithms considered in this paper. The number of incorrect calculations equaled to 8% of all calculations makes proposed algorithm suitable for different personal non-medical applications.

Current version of the proposed algorithm was successfully implemented in Pulse Detector application that is developed for Symbian platform and can be downloaded from the Nokia Store: *http://store.ovi.com/content/314173*. Pulse Detector for now has more than 40000 downloads.

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