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Measuring Heart rate with Optical sensor

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Measuring Heart rate with Optical sensor

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Inhoud

Introduction

The problem addressed in this report is to verify the possibility of using an optical sensor in SaxShirt in order to extract the heart rate. There are specifically three questions that we try to address. 1) How is it possible to extract heart rate (BPM) from the optical sensor? 2) Is it possible to use the sensor for extracting BPM during movement? 3) Is the heart rate measured in this way useful for measuring other higher-level parameters such as heart rate coherence and heart rate variability? For this purpose, we have performed tests with the sensor placed on different spots and the data was analyzed to see if heart rate can be extracted from the sensor measurements.

1. Optical heart rate sensor

The optical heart rate sensor chosen for this purpose is an off-the-shelf product which can be used being coupled with an Arduino Uno board [1]. There is a processing sketch that shows the output of the arduino serial port. The method of finding the BPM in the arduino code is finding the number of peaks in the time series. We have tested the pulse sensor to see if it operates as expected.The original code implemented does not seem to provide any results (at least for a number of subjects). In order to separately analyse the data, the arduino code was modified so that the output of the serial port is logged into a separate file. The results were further processed in matlab. Table 1 summarizes the test subjects and data collected from them while performing different activties.

User	Gender	Min	Max	Range	Activity
Maud	Female	299	313	14	Sitting
Jaap	Male	360	530	190	Sitting
Noortje	Female	466	480	14	Standing
Noortje	Female	466	486	20	Walking
Noortje	Female	455	497	42	Running
Mitra	Female	476	480	4	Sitting
Mitra	Female	410	520	110	Running
Siavash	Male	410	500	90	Sitting
Siavash	Male	450	490	40	Walking
Siavash	Male	250	700	450	Running

Table 1. Summary of the data acquired from different participants.

Generally, it can be seen that the signal amplitude ranges from subject to subject depending also on the activtiy. The differences can be explained by considering the effect of blood pressure. The general blood pressure of female subjects is lower than that of male subjects and by increasing the activtiy level blood pressure rises. Higher blood pressure increases the signal amplitude range and make the heart beat more detectable.

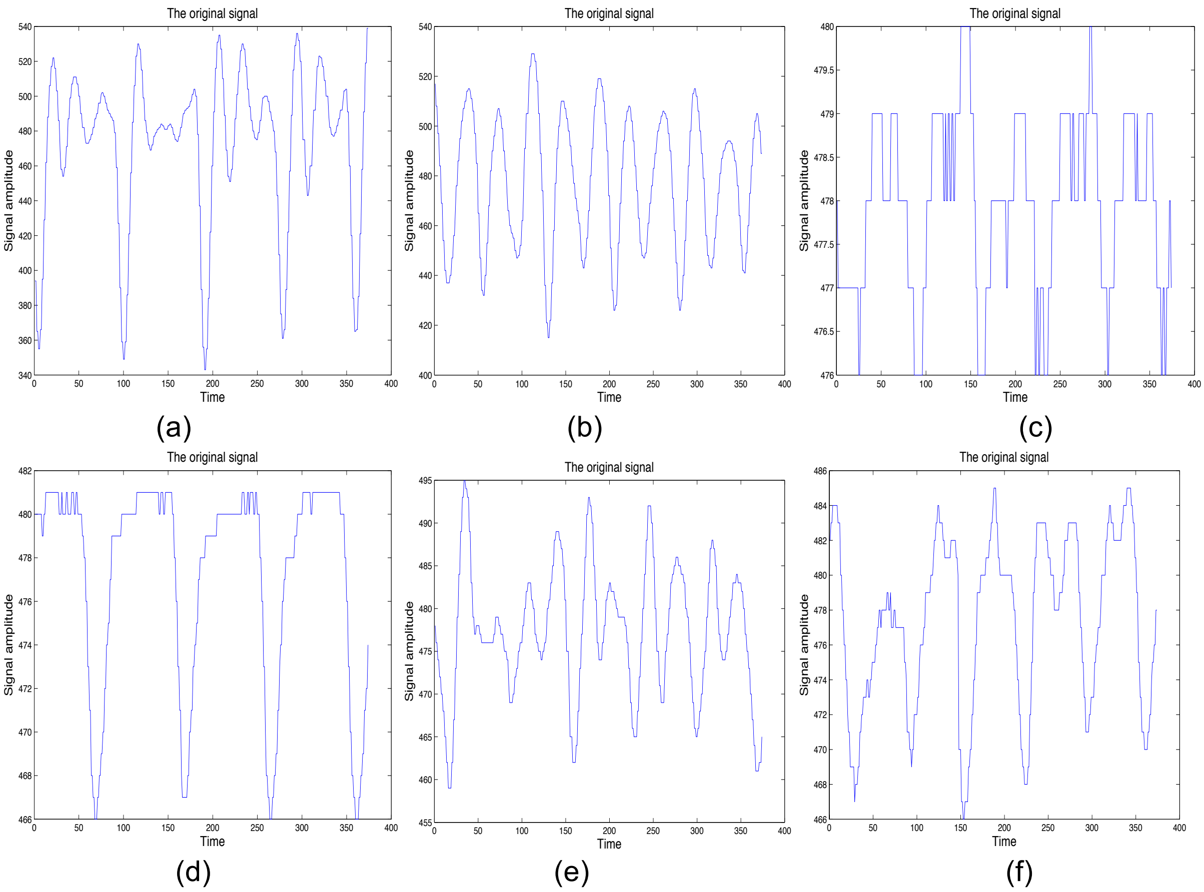


Figure 1. Visual representation of data from different participants. a) Jaap-sitting b) Mitra-running c) Mitra-sitting d) Noortje-standing e)Noortje running f) Noortje walking.

2. Calculating Heart rate

There is an algorithm already implemented as part of the arduino code provided with the sensor. The problem with the code is that it does not work for female participants. Furthermore, this method does not seem ideal as the effect of noise is not effectively neutralized.

As seen in Figure 1, the heart beat pattern for each subject during different activities is different. Sometimes, the peak (of R-wave and T-wave) are more visible (Figure 1.a), while sometimes, the signal is more in form of Hills without a dominant peak (Figure 1.d). This diversity in the patterns make the use of threshold based techniques not suitable.
The only similarity between all the above graphs is their periodic pattern. In case we could measure the periodicity in the graph over few seconds, the average heart rate would be easily calculated. This saves the effort of finding an optimal threshold and dealing with occasional noise. Periodicity detection techniques such as fourier analysis and autocorrelation can be useful in this case.

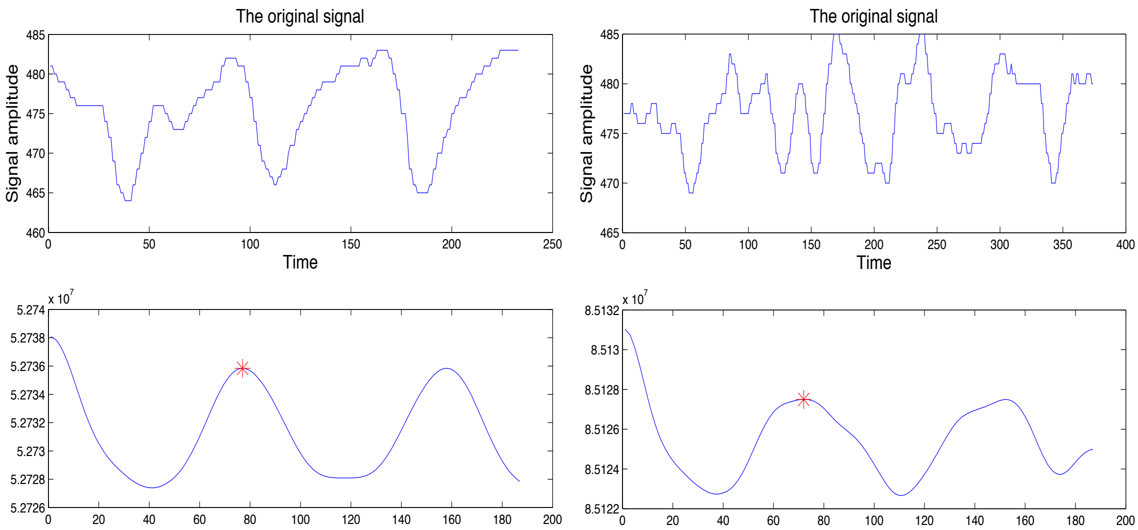
2.1. Circular Autocorrelation

We have used circular autocorrelation [2] to measure the difference between consequtive periodic peaks in the graph. Circlular autocorrelation is one of the well-known techniques in measuring periodicities in time series. The output of the autocorrelations represents the self-similarity of the graph to itself in different lags. The first dominant peak in the circular-autocorreleogram represents the dominant periodicity in the time-series and the rest of the peaks with the same height are the integer multiplies of the dominant period.
Circular-autocorrelation function ($CACF$) of a time series A of length n is calculated through the following equation:

$$CACF(\tau) = \sum_{i=1}^{n} a_i . a_{i+\tau}$$

2.2. Extracting Heart rate from Circular-Autocorrelation graph

In order to extract the first dominant peak in the circular-autocoreleogram a peak detection algorithm is written. Figure 2 represnts the autocoreleogram of the signal both when the heart rate is visible and when there exists a considerable amount of movement artifacts. The peaks detected in the autocoreleogram for the both graphs is adequately in the same range.



(a) (b)

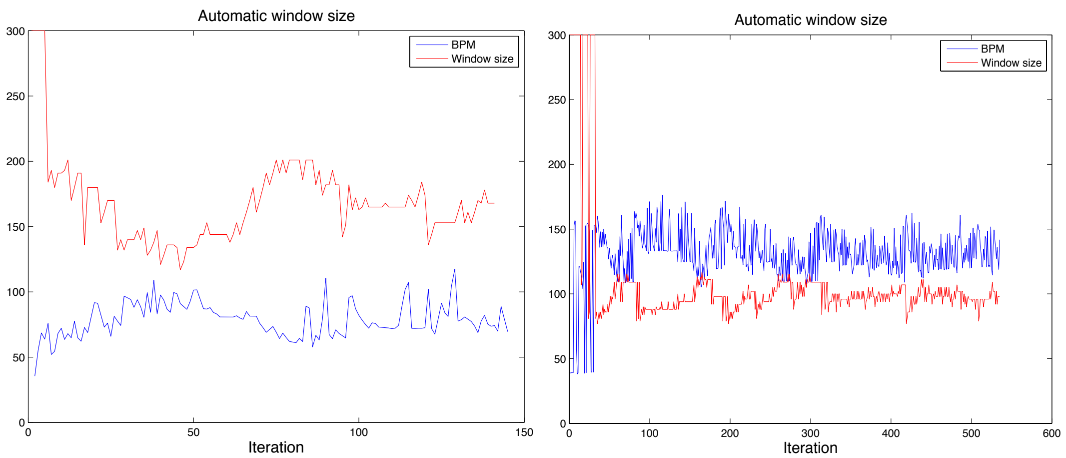
Figure 2. Detection of the heart rate repetition period (a) Without noise (b) With movement noise.

Having the window size (ws). The detected period τ from the autocorreleogram can be later changed into BPM through the following equation:

$$BPM = 60 \times ws/\tau$$

2.3. Is the results suitable for higher level analysis?

By using Autocorrelation, it is possible to provide BPM close to heart rate of the user. By always covering 3-4 heart beats in a window an average heart rate is calculated which can be used to inform the user about the heart rate zone. In order to have a higher level indicator such as heart rate variability and heart rate coherence it is needed that every beat to beat interval over a considerable amount of time is calculated.
In order to use the auto-correlation based technique, we have to set the window size such that it only covers two consecutive heart-beats. As the heart-beat differs from person to person and changes from activtiy to activity this window size cannot be fixed.
In order to set the window size dynamically, we further wrote an algorithm. This algortithm starts with a fixed-size window with the length of about 3 seconds. This initial value insures that with the lowest heart rate there exists 2-3 beats in the window. In the future iterations, the window size is set based on the median of a number of previous heart rates measured. This way, we can be assured that each window only covers two consecutive beats. Figure 3 represents the function of the dynamic window size detection algorithm.



(a) (b)

Figure 3. Dynamic window size adjustment for measurng beat to beat interval (a) subject walking (b) subject running.

3. Sensor spot

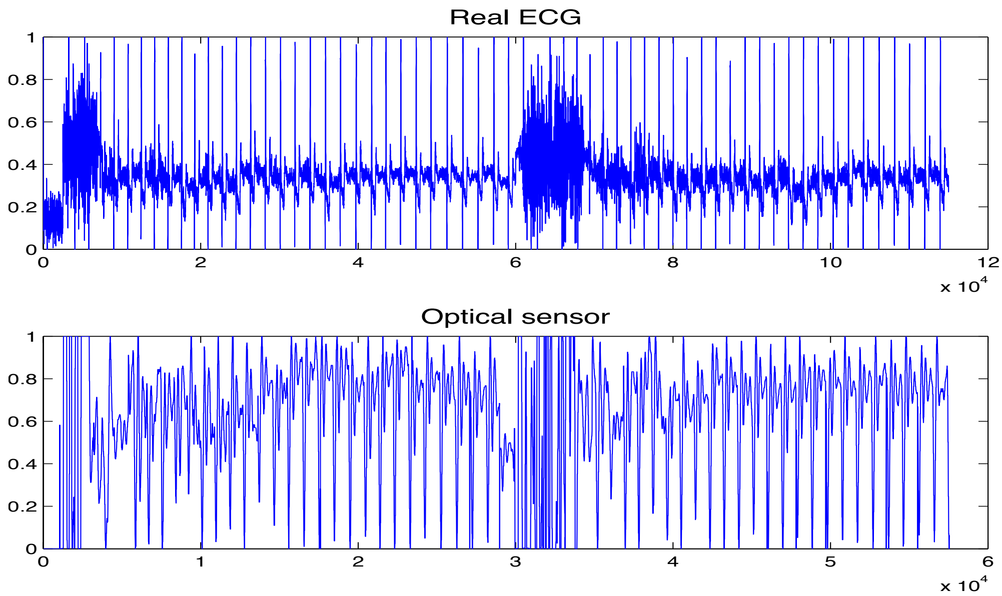
Generally, as the blood vessels exist everywhere, it is possible to place sensor anywhere. Normally, commercial pulse oximeters work by placement on earlobes and finger as the amplitude of the signal is higher due to thinness of skin. However, with respect to the design requirements of the shirt, two candidate spots are chosen 1) Under the chest bone, 2) bisepts. In order to determine the best spot for placing the sensor we collected data of these two spots and calculated the BPM over twenty consecutive windows of size 250 samples. Results are presented in Table 2 bellow. As seen, with respect to the number of valid measurements and the signal range, better results can be presented by placing the sesnor under the chest bone.

Spot	Sitting			Walking		
	Valid	Invalid	Range	Valid	Invalid	Range
Arm	18	2	475-480	11	9	470-485
Chest	20	20	470-480	14	6	385-630

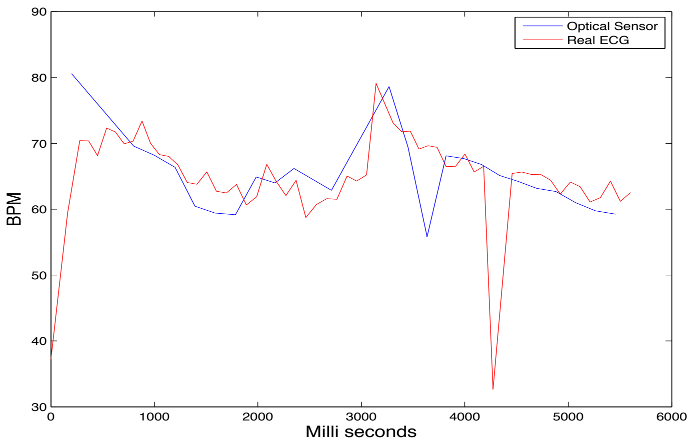
Table 2. Comparison of heart rate detection algorithm on data of two candidate spots

4. Is optical sensor as good as ECG?

The sensor is composed of an optical transceiver. Once placed on the skin, the change in the light emited and reflected can be interpreted in terms of heart beat. The heart beat measured from ECG devices represents electrical activity of the heart muscle. Measuring heart rate from an optical sensor is, however, also affected by blood pressure.Therefore, the accuracy of heart beat measured through optical is still a question. Graphs below represent the comparison between heart beat measured by optical sensor and a TMSI wireless ECG device [3]. The optical sensor measurements were taken by placing the sensor on finger and the ECG electrodes were attached to the chest. Both signals are synchronized by a synchronous muscle activtiy in the beging and middle of the test. As the signals are acquired from different devices, with different clocks, there was no better way of synchronizing signals. After signals are acquired, both are normalised between [0,1]. A very basic peak detection algorithm is used to acquire peaks over (ECG) and below (optical sensor) a threshold. The valid heart beats extracted from both signals are presented in Figure 4.a. As seen, the heart beat measured from both sensor types are very close. However, they are not completely equal. The variability in the measurements from optical sensor is less.



(a)



(b)

Figure 4. a) Comparison of data acquired from ECG and optical sensor b) BPM extracted from two technologies.

5. Conclusions

In this report, we have adressed the use of optical heart rate sensor in SaxShirt. The results of analysis of the signal acquired from the sensor, suggests that after analysis a heart rate close the average heart beat of the user can be calculated. By using autocorelaion a certain level of movement artifacts can be neutralized when the sensor is placed in the shirt. Using a dynamic window size detection algorithm, peak to peak heart beat interval can also be measured. However, the higher level parameters extracted from these measures are not as accurate as the ones extracted from real ECG devices.

6. References

[1] (2014). *Optical pulse sensor*. Available: http://pulsesensor.myshopify.com/
[2] (2014). *Autocorrelation.* Available: http://en.wikipedia.org/wiki/Autocorrelation
[3] (2014). *ECG equipments*. Available: http://www.tmsi.com/