34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

HRV based Health&Sport Markers Using Video from the Face*

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Abstract— **Heart Rate Variability (HRV) is an indicator of health status in the general population and of adaptation to stress in athletes. In this paper we compare the performance of two systems to measure HRV: (1) A commercial system based on recording the physiological cardiac signal with (2) A computer vision system that uses a standard video images of the face to estimate RR from changes in skin color of the face. We show that the computer vision system performs surprisingly well. It estimates individual RR intervals in a non-invasive manner and with error levels comparable to those achieved by the physiological based system.**

I. INTRODUCTION

The analysis of heart rate variability (HRV) is gaining interest recently because of the fact that it provides information about the activity of the autonomous nervous system and because of its potential to help diagnose and monitor cardiovascular disorders. HRV is defined as the change in the duration of time intervals between consecutive heartbeats [1]. Although this is not a recent discovery, the continuous advances in computer and electronic technology have allowed for reliable, and inexpensive ways to register HRV thus making it potentially useful in field situations. HRV is emerging as an excellent indicator of health status, which brings together the advantages of being objective, reliable, and very easy to obtain [2]. For the general population HRV has been shown to be a useful indicator of general health, fitness level, and psychological stress level [3, 4, 5]. In all cases health level, wellness, and optimal adaptation to physical activity correlate with high HRV, while disorders, non-adaptation to stress (physical or psychological), excessive physical burden, overtraining or poor fitness are associated with low HRV [6].

In recent years wearable health monitoring devices have attracted increasing interest, both in research and industry. The ability to continuously monitor physiological signals in daily life conditions is of particular importance. Thus, these devices need to be non-intrusive, easy to use, comfortable to wear, efficient in power consumption, and privacy compliant. Recently several papers have appeared in the literature that suggesting that standard video cameras can be used unobtrusively to measure heart rate. The variations in the face of the patients due to photopletismographyc and color changes can produce small fluctuations in the RGB components of the video signal [7, 8, 9 ,10]. However, it is unclear whether video images of the face provide enough resolution to reliably measure HRV. Several obstacles arise: (1) The ambient light can interfere with the recorded signals. Fluorescent lamps for example, create an interference at a frequency of 100 Hz (Europe) that create important aliasing artifacts in the video signal. (2) Face motion due to rigid rotation and translation of the face, or non-rigid changes of facial expression, can generate noise that overwhelms the changes in skin color due to cardiovascular activity. (3) The frame rate in the standard cameras is quite small (between 15 Hz to 30 Hz) thus reducing the temporal resolution for estimating RR intervals. In this document we propose a video based system to estimate RR intervals, and HRV parameters. We compare the performance of the system to that of a popular commercial system based on recording the physiological cardiac signal trough a chest band with electrodes. Our focus is on methods to solve the aforementioned low sampling frequency of typical video cameras. We show that the proposed computer vision system can achieve levels of performance in the estimation of RR intervals and HRV parameters comparable to that of the physiological based systems.

II. PROCEDURE

A. Sample

The initial sample was 8 men and 3 women (age between 18 and 50 years old). Participants must did not take any kind of medication and did not show abnormal blood pressure or electrocardiographic patterns. All participants were volunteers and provided informed consent. The final sample consisted of 5 men and 3 women (age: 34.2 ± 11.1 yr). The data from three men was rejected because they moved too much during the video recording.

B. Instruments

The face of the subjects was recorded for 5 minutes with a compact camera (Canon Ixus 80is) with a resolution of 640x480 in AVI format. Simultaneously an inductive band (SleepSense, S.L.P. Ltd.) and a Polar chest band (T61, Polar Electro Oy) were strapped around the chest of the subject to record respiratory and RR signals. The respiratory signal from the inductive band was amplified and acquired with A/D USB card (National Instruments, NI USB-6008). The RR signal from the Polar band was acquired with an OEM

*Research supported by grants PSI2008-06417-C03/PSIC and PSI2011-29807-C02/PSIC from Spanish Government.

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receiver from Polar (RE07S_ILNI_C) and the RR interval pulses measured with a 8 bit microcontroller (PIC18F1333, Arizona Microchip) and transferred via USB to a PC. A custom made software developed in LabView was used to acquire and synchronize both signals and to record to a text file. The video files, RR and respiratory signals were analyzed with MATLAB.

C. Procedure

Each participant wore the two elastic chest bands placed below the chest muscles. Participants had to do a HRV-5min Test at rest in a sitting position (in a isolated and quiet room with controlled illumination). During the test period the participants were asked to sat down and relax on a comfortable armchair, eyes closed. They were asked to avoid making head or body movements and to synchronize their breathing to an electronic metronome that operated at 12 cycles/min. A video of the complete face was recorded during all the HRV-5min test and was saved in a non-compressed RGB format. The illumination conditions were all the times the same, with a 15 w light (Sylvania, coolwhite 840) maintained at one meter to the participant face.

III. HRV ANALYSIS

The R-R intervals, i.e., the time between the R peaks of consecutive QRS complexes was recorded by the Labview software, and automatically checked for artifacts. Occasional ectopic beats were identified and replaced with interpolated R-R intervals. HRV analysis was performed by the Matlab software for the two RR signals (video and Polar) on the 5 min controlled breathing in the sitting position. The mean of R-R intervals, the standard deviation of normal R-R intervals (SDNN), the percentage of successive R-R differences greater than 50 ms (pNN50), and the root-mean-square difference of successive normal R-R intervals (RMSSD) were calculated for the 5-min period. Power frequency analysis of the 5-min recordings was performed sequentially with a fast Fourier transform based on a non parametric algorithm with a Welsh window after the ectopic-free data is detrended and resampled at 4 Hz with a cubic spline interpolation [11]. The power densities in the VLF band (0.00-0.04Hz), the LF band (0.04–0.15Hz) and the HF band (0.15–0.40 Hz) were calculated from each 5-min spectrum by integrating the spectral power density in the respective frequency bands. The different HRV indexes, SDNN, RMSSD, pNN50, LF, HF, and VLF were calculated and saved with the participant codes.

IV. COMPUTER VISION ANALYSIS

A. RGB decomposition from AVI file

The analysis of the video signal was done in two steps:

(1) The face of the subject was segmented manually adjusting a rectangle to cover the maximum area of the face. While this part of the process was done manually, it could be easily automated using current computer vision based face detection algorithms [12]. For each frame the average of the R, G and B pixels of the segmented face area was calculated. Three temporal signals with a sampling rate equal to the frame rate are obtained. The cardiac signal is present in the three signals, but the G component had the highest amplitude. Thus, it was used to obtain the cardiac information. The G channel signal was bandpass filtered between 0.4 Hz to 10 Hz with a Butterwoth second order filter to remove low frequency components (respiration and movements) and high frequency components (ambient light flickering, electronic noise in the optical sensor) (Figure 1).

(2) In order to improve the signal noise ratio only the pixels in the original video that had a high correlation coefficient with the previous G filtered signal were averaged. To accomplish this, each frame was divided in blocks of 20x20 pixels and the G component was averaged for each block. The 32x24 signals obtained from each frame were crosscorrelated with the previous G filtered signal. Only the signals blocks that had a correlation coefficient higher than specific value are averaged (for example 0.7). Figure 2 shows an image of the correlation coefficient for each block. As can be seen some parts of the face (front, cheeks and mouth) had more heart beat signal than others (nose, eyes).

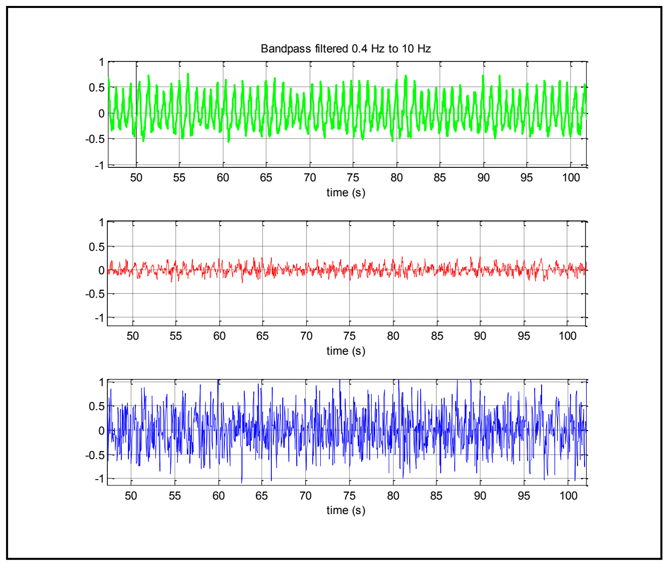

Figure 1. G,R and B signal components of face video (50 sec) , with mean removed and bandpass filtered (0.4 Hz to 10 Hz). We can clearly observe the RR peaks in the green channel.

B. Filter of artifacts and RR calculation

The G component obtained from the blocks with higher correlation was used to the obtain the RR signal. The signal was first resampled form 30 Hz to 1 kHz to improve the temporal resolution. Then, the signal was bandpass filtered between 1 Hz to 3 Hz with a second order Butterworth filter and compared with a threshold 0.8 times the its standard deviation. The local maxima in the resulting signal were used as estimates of the beat position. The RR series was obtained by differentiation of the beat positions.

C. Synchronization of the two RR sources

The RR signal from the video signal is aligned automatically with the RR signal from the Polar band in order to be compared (Figure 3).

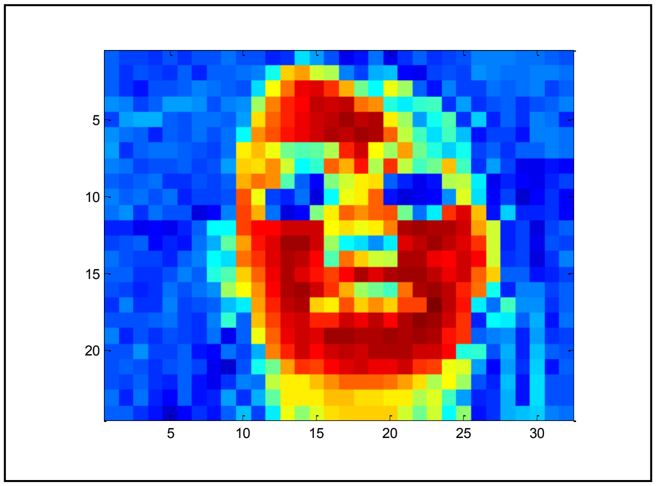

Figure 2. Correlation coefficient for each image block with the reference signal for a 5min video-face. The dark red parts (front, cheeks and chin) have more cardiac component than others (nose, eyes).

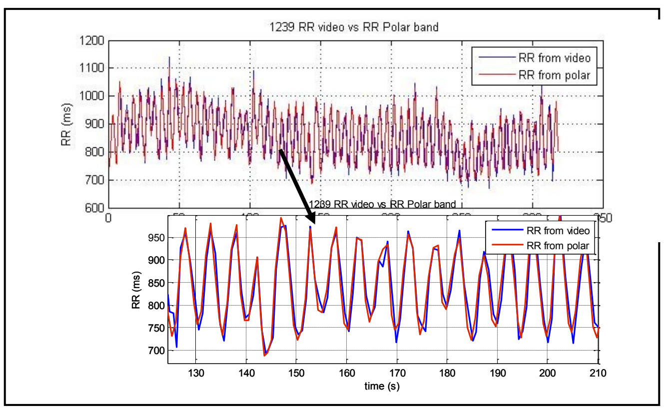

Figure 3. Synchronization of the video and RR signals for a single case (full record and 80 s zoom). We can observe the respiratory sinus arrhythmia (RSA) produced by the forced breathing at 0.2 Hz (12 peaks every 60 sec).

V. RR INTERVAL COMPARISON: VIDEO VS POLAR

Figure 4 shows the correlation between the RR estimates from the Polar system and from video for a representative case, and Figure 5 shows Bland-Altman plots for RR intervals for the same single case. Figures 4 and 5 represent the accuracy of cardiac beat detection for a specific subject. All participants showed similar results. Table 1 and Figure 6 show good correlations for the HRV parameters between video and Polar systems (calculated from the respective RR curves) for the entire group.

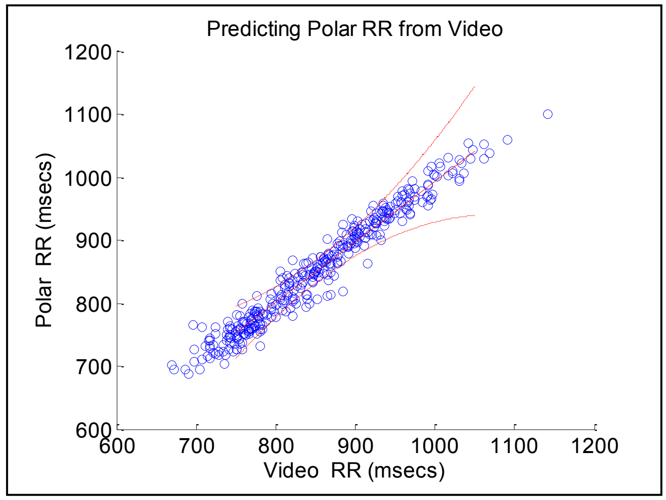

Figure 4. Correlation of the RR intervals from video and Polar (single subject).

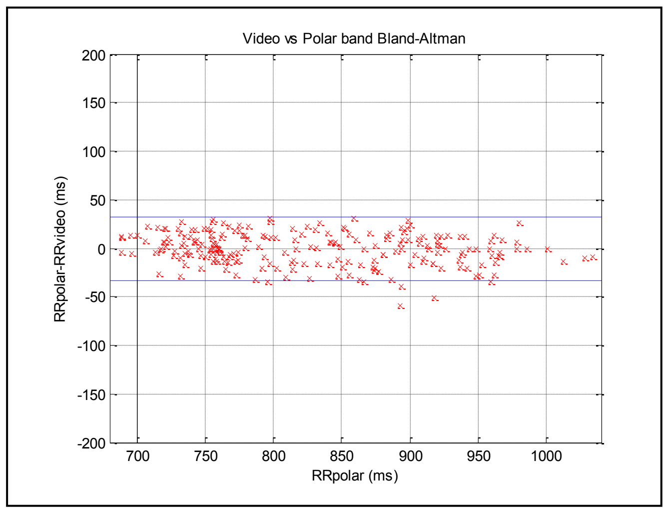

Figure 5. Bland-Altman plot demonstrating the agreement between RR intervals from video and Polar (single subject). The lines represent the mean and 95% limits of agreement. X axis represents RR average by video and Polar. Y axis represents RR difference between Polar and video.

TABLE I. HRV CORRELATIONS BETWEEN VIDEO AND POLAR PARAMETERS (N=8).

HRV Parameter [a]	r (Pearson) [b]
RRmean	0.999**
SDNN	0.953**
RMSSD	0.754*
Pnn50	0.798*
VLF	0.996**
LF	0.995**
HF	0.996**

a. See part III for parameter definitions

b. ** p<.01 * p<.05

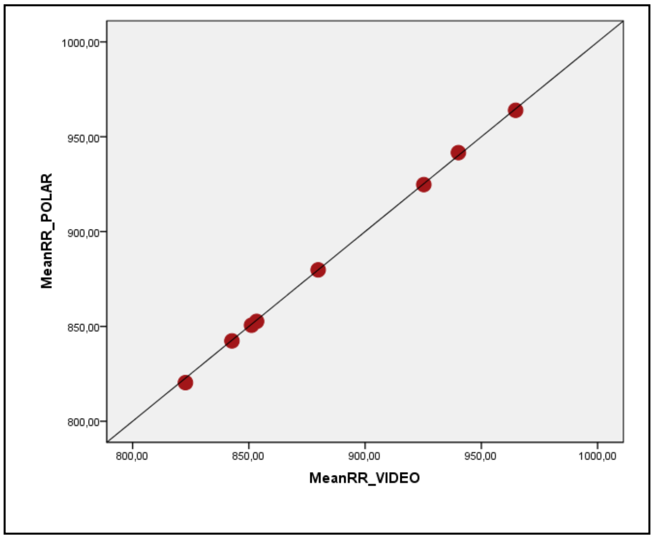

Figure 6. Correlation of the RR mean between video and Polar for the final sample (n=8).

VI. CONCLUSION

This work demonstrates the feasibility of using standard video signal of the face to record RR intervals. The proposed approach can provide HRV parameter estimates with accuracy comparable to that of current commercial systems based on. One of the most important aspects needed to achieve reliable estimates of RR interval from video was an active selection of the most informative pixels. Here we showed that a simple auto-correlation scheme could be used for this purpose, with very good results. Our work suggests that HRV analysis could indeed be performed via video. The advantage of such an approach is that current video cameras are inexpensive, unobtrusive (do not require cables attached to the body) and available in a wide range of daily life artifacts, from laptops, to telephones. Video based HRV analysis could be relevant in applications that require ambulatory monitoring of cardio-respiratory health or stress induced by effort (high performance sports). The standard HRV test is performed at resting, even in sports evaluations. One of the difficulties we encountered was the need to detect and compensate for face movements in people that could not maintain their face still. For example, the three men who where rejected in our study showed too much movement during the video recording and presented lower RR correlation with Polar system. Current face detection and tracking algorithms could be used to this effect. We must emphasise the importance of obtaining a good RR synchronization between the Video and Polar signals in order to be compared, and suggest the improvement of automatic alignment algorithms.

ACKNOWLEDGMENT

The aim of this study has been achieved through collaboration with the Machine Perception Laboratory (UCSD, San Diego, USA).

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