Cardiac Pulse Enhancement in Camera-Based Monitoring – A Spectral Analysis of Common Linear Transformations

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Introduction

Changes in optical absorption of the human skin based on the blood volume pulse can be measured by using cameras [1]. The technique, referred to as camera-based photoplethysmography (PPG), provides a contactless mean to monitor vital parameters. Since contactless measurements are sensitive to a broad range of artifacts, transformations like Independent Component Analysis (ICA) or Principal Component Analysis (PCA) are often used to separate usable signal portions from noise and artifacts [2].

This contribution addresses the usefulness of ICA and PCA during camera-based clinical intensive care monitoring in terms of assessing the pulse rate in the frequency domain.

Material and Methods

Material

Video data was recorded using an industrial camera (IDS UI-3370CP-C-HQ, 100 fps, 420x320 pixels, RGB 3x12 bit). The camera was placed at a distance of approximately 60 cm to patients' face. Due to advantageous absorption properties, the green channel was selected for this analysis [3]. Recordings of overall 3000s length of three recumbent cardiovascular patients (during recovery after heart surgery) were analyzed. A reference PPG was simultaneously recorded by using a clinical finger PPG sensor.

Methods

The biosignals extracted from the video data were obtained from three manually selected static 32x32 pixels regions of interest (ROI) on patients' forehead by calculating the mean brightness of each ROI for the successive images. Choosing only one wavelength and a narrow region of the patients face was intended to ensure a linear relation between the three observed signals to justify the application of linear transformations. The time series were examined using consecutive segments of 10s duration (50% overlap). Common transformations (FastICA with tanh-nonlinearity [4], JADE-ICA, PCA [5]) were applied to the extracted segments (with/without 7.5 Hz Butterworth lowpass prefiltering). The transformations were computed symmetrically, thus obtaining as many output components as input signals (i.e. three components). The quality of the signal regarding the pulse was assessed calculating the SNR (following [2]) of all signals (before/after transformation) with zero-padding (giving 2^{12} sample points each to FFT).

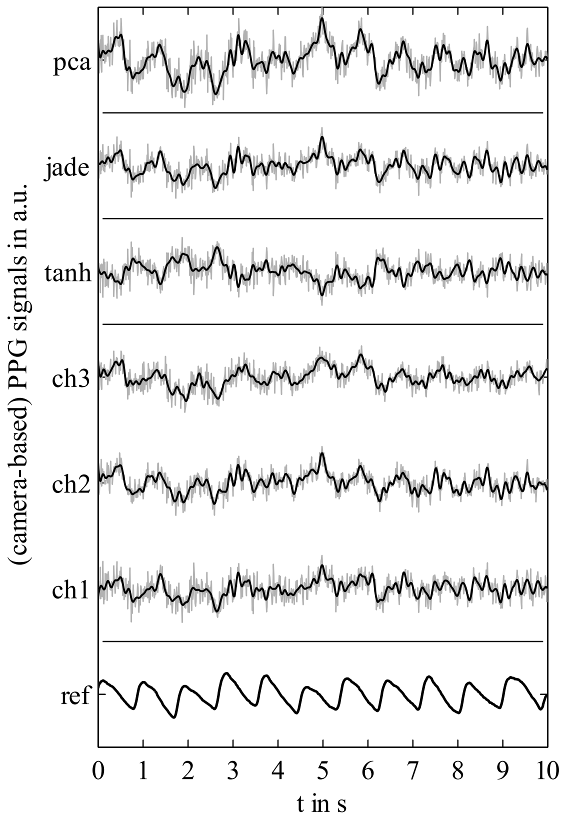

Fig. 1: Effect (a) of common linear transformations (PCA,ICA – best output component each) on camera-based PPG recordings (*ch1-ch3* forehead ROIs) – original extracted (grey) and lowpass filtered (black) time series, reference PPG signal (*ref*) shown in the bottom panel.

Results

We found that the question whether common linear transformations lead to a performance increase can only be answered individually. Figure 1 shows time series examples of extracted and transformed signals in case of a good-quality recording. In this example, no obvious improvement of signal quality (e.g. noise separation from the respective best component (pca/jade/tanh) could be obtained. Figure 3 supports this finding by a spectral representation of these signals including the SNR values.

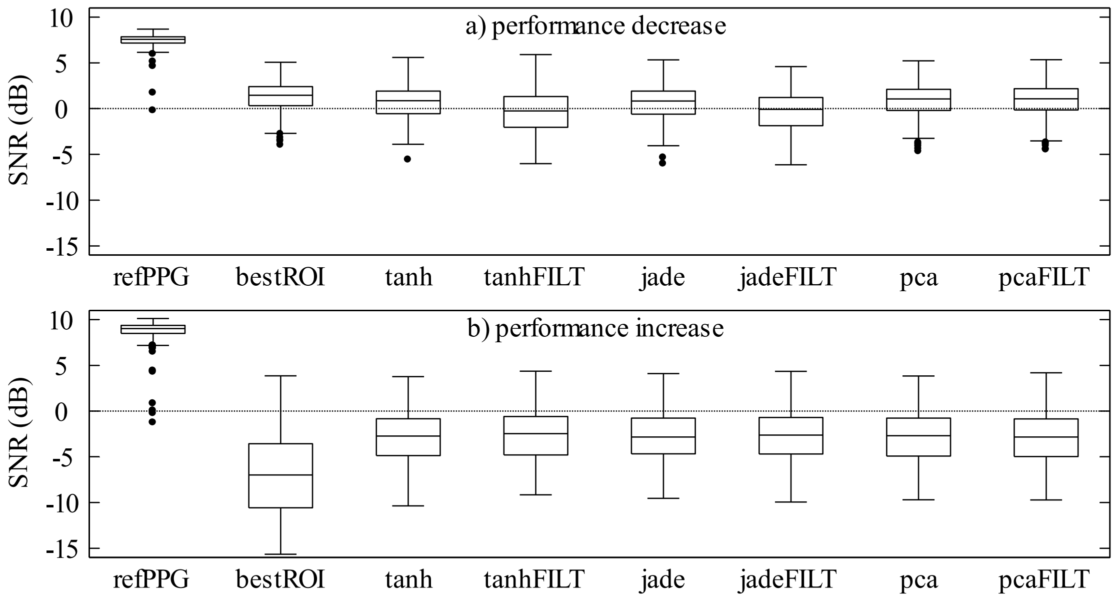

Fig. 2: Boxplots containing SNR of *refPPG*: reference PPG sensor, *bestROI*: best SNR of three input ROIs, *tanh/jade/pca*: transformation output (best SNR output each), *suffix FILT*: using prefiltered data before transformation.

Figure 2 shows the SNR results of two groups consisting of (a) one patient with a 1500s recording and (b) two patients with another 1500s of recordings. In case of good-quality input ROIs with SNR > 0 dB (a), the spectral quality of the cardiac pulse was slightly decreased using the examined transformations. In this group, the PCA showed a slightly better performance than ICA. Moreover, using a noise suppressing lowpass filter before transformation further decreased the performance of ICA algorithms. In case of an inferior input ROI quality with SNR < 0 dB (b), an increase in SNR could be observed by applying the transformations. In addition, some (b) portions showed ICA performing best. Figure 4 shows time series examples of extracted and transformed signals in case of a beneficial application of PCA/ICA in terms of increasing the SNR of the transformation components compared to the best input signal. Despite slightly improving the time course of the camera-based PPG especially by using ICA, again no obvious high frequency noise separation (grey signals) in the respective best component could be observed. Figure 5 depicts the corresponding spectral representation of these signals including the SNR values.

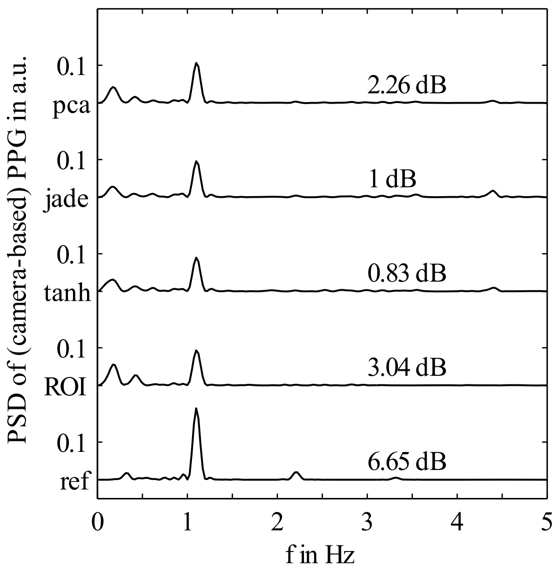

Fig. 3: Effect (a) of common linear transformations (PCA,ICA – best output component each) on power spectral density (PSD) of camera-based PPG (*ROI* shows best SNR forehead ROI), reference PPG signal (ref).

Discussion

We used an uniform ROI distribution on patients' foreheads (left,center,right) to extract the camera-based PPG signals. The placement of the ROIs serving as input of spatial linear transformations should be considered more carefully due to possible effects of the face symmetry in context with the blood supply. Namely, pure spatial transformations do not account for temporally delayed inputs but asymmetric blood supply could cause different arrival times of the blood volume pulse in different face sides. On the one hand, adding a temporal dimension to the transformations or on the other hand, restricting the ROI placement to only one single face side could improve the performance of the transformations. Since adding a temporal dimension is equivalent to convolution in the mixing process of usable signal portions with noise, one could also apply a transformation in frequency space [6].

The interesting effect of a decreasing SNR of ICA after lowpass prefiltering of the input signals could be a result of the usage of signals higher order statistics which are altered by a lowpass filter.

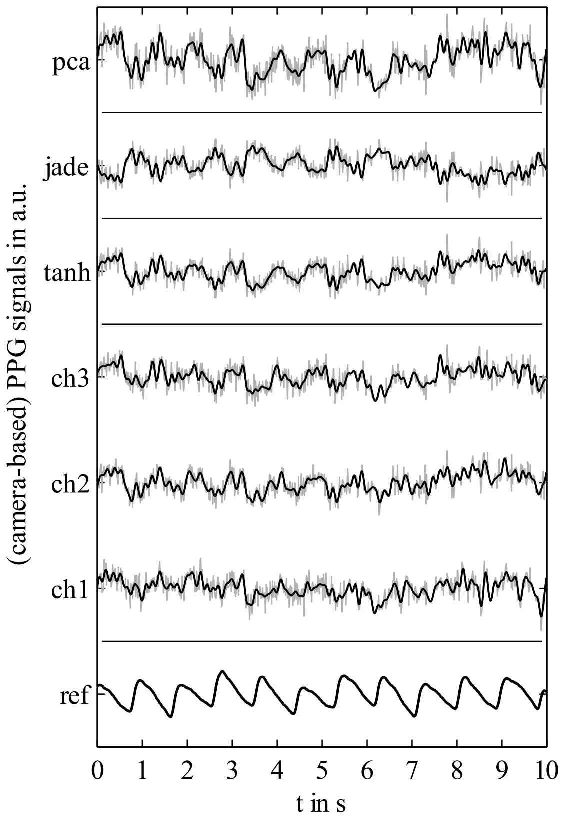

Fig. 4: Effect (b) of common linear transformations (PCA,ICA – best output component each) on camera-based PPG recordings (*ch1*-*ch3* forehead ROIs) – original extracted (grey) and lowpass filtered (black) time series, reference PPG signal (*ref*) shown in the bottom panel.

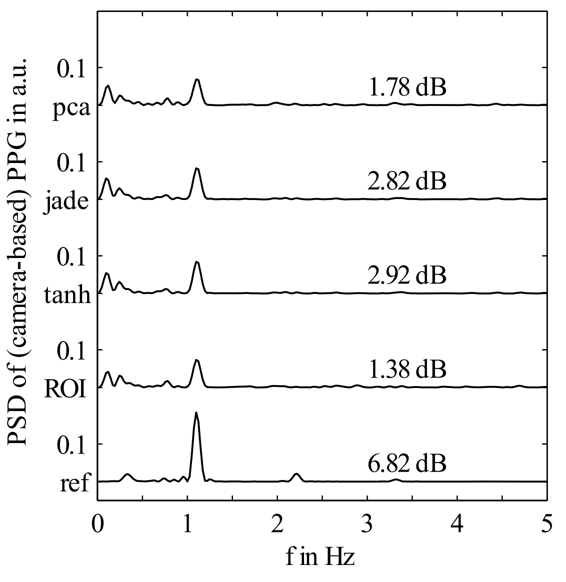

Fig. 5: Effect (b) of common linear transformations (PCA,ICA – best output component each) on power spectral density (PSD) of camera-based PPG (*ROI* shows best SNR forehead ROI), reference PPG signal (ref).

Conclusion

This contribution showed that cardiac pulse enhancement using common linear transformations like ICA/PCA in context with camera-based PPG is no straightforward task. Due to this ambiguous behavior, future investigations should include frequency domain transformations, since suchlike methods could more directly address distinct frequency components (e.g. the pulse), and thus, increase the SNR.

Literature

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