Camera-based heart rate monitoring in highly dynamic light conditions

Vincent Jeanne, Michel Asselman, Bert den Brinker, Murtaza Bulut
Philips Research, Eindhoven, The Netherlands
Email: vincent.jeanne@philips.com

***Abstract*—Recent advances in biomedical engineering have shown that heart rate can be monitored remotely using regular RGB cameras by analyzing minute skin color changes caused by periodic blood flow. In this paper an infrared-based alternative for light-robust camera-based heart rate measurements suitable for automotive applications is presented. The results obtained by this system show high accuracy (RMSE $<$ 1BPM under disco-light) and a correlation score above 0.99 when compared with a reference measurement method. The proposed system enables new applications in the automotive field, especially since heart rate measurement can be integrated with other camera-based driver monitoring solutions like eye tracking.**

I. Introduction

Advances in computer vision have enabled new applications in the automotive area. Cameras are used in advanced driver assist systems that monitor the environment to increase safety and comfort by performing tasks like lane departure and traffic signs detection as well as parking assistance. Cameras are also used inside the vehicle environment for monitoring the driver. Numerous research on this topic showed that state-of-the-art computer vision techniques like face pose estimation and eye tracking [1] can enable applications in the area of driver fatigue [2] and vigilance [3] monitoring.

Recent advances in the field of biomedical engineering have shown that it is possible to remotely measure heart rate using regular RGB cameras [4], [5]. Heart rate is captured using remote photoplethysmography (remote PPG), which is an extension of the contact photoplethysmography developed in the 1930s by Hertzman [6]. The principle behind this technology is that the light reflected from the skin is modulated according to the specific absorption spectrum of the hemoglobin, the main constituent of blood. Each time the heart beats, a new blood flow reaches the skin leading to minute variations of the skin color, so called *micro-blushes*. While these *micro-blushes* cannot be observed by the human eye, regular camera and dedicated algorithms allow their extraction.

Results reported on remote PPG-based heart rate measurement have so far shown good accuracy under stable light conditions for situations ranging from monitoring stationary subjects [4], [5] to monitoring during physical exercises [7], [8]. However, since remote PPG is based on the analysis of minute color changes, its performance in an automotive setting using an RGB implementation is questionable. The reason for concern is the highly dynamic and unpredictable environment especially in terms of lighting conditions which can vary from (i) full to cloudy sunlight, (ii) natural to artificial light and (iii) presence to absence of light. The amount and spectral content of the light available in the environment are the main factors that need to be accounted for to achieve light robust camera-based heart rate measurements.

In this paper we describe an infrared-based implementation of remote PPG measurement suitable for the automotive environment and present results obtained under highly dynamic light conditions.

II. Infrared-based remote PPG

As in full darkness RGB cameras do not function at all, we designed an infrared-based remote PPG solution that uses a dedicated light source. A light source emitting in the infrared region of the spectrum (700nm to 1000nm) (i) ensures user comfort, as it is invisible to human eye, and (ii) allows remote PPG measurements as the infrared region is also modulated by the blood pulse. Disturbances in the measurement caused by external light sources are largely eliminated by using a narrow-band optical filter. The infrared light source is flashed in sync with the camera frame rate. The flash duration and intensity are optimized such that the total projected optical power complies with official safety regulations [9].

The proposed IR-based remote PPG system uses hardware of the Antisleep system [10], comprising an infrared sensitive monochrome camera and two light units emitting in the infrared domain. The extraction of the remote PPG

Fig. 1. Example of the lighting conditions during a 10 seconds time interval.

waveform is performed by applying spatio-temporal processing techniques similar to [4]. The selection of the measurement area is performed using a state-of-the-art face detector. To ensure that the processing takes into account only relevant pixels a skin detection step is added. The extraction of the heart rate values from the raw waveform is based on Fourier analysis of a 512 data point sliding window.

III. Experiments

To verify the robustness of the designed system, IR-based heart rate measurements were compared to reference measurements under different light conditions in laboratory settings. The acquisition of the reference heart rate measurements was performed by a pulse oximeter from Contec Medical Systems (CMS50E). Dedicated software was used to synchronize the reference measurements with the video recordings. The experiments were conducted on four healthy volunteers. Subjects were asked to sit still on a chair for the duration of the recording (2 minutes). The camera was aimed at the subject's face with a distance between camera and subject of approximately 0.6 meters. The video recordings were made at 20 frames per seconds with a resolution of 120×180 pixels obtained by pixel binning.

Dramatic light variations were introduced to mimic the automotive environment. These variations were produced by controlling a set of three light sources of which two exhibit a narrow spectrum and one a wide spectrum mimicking artificial street light and sunlight, respectively. Random light changes included slow intensity and color variations up to very high frequency modulation resembling a disco environment. Figure 1 shows an example of a set of consecutive frames selected from one of the recordings.

IV. Results

The presented results are expressed in terms of correlation scores (r-values) and root-mean-square-errors (RMSE) in beats per minute (BPM) compared with the reference contact heart rate measurements. Figure 2 shows the heart rate values obtained by the IR-based remote PPG system (continuous line - blue) and the reference measurement (diamond shapes - red) for the four subjects. The measurements collected with the IR-based remote PPG system show almost one to one match and a high correlation with the reference measurements. The maximum observed deviation from the reference is about 5.8 BPM. The r-value and RMSE obtained are 0.9978 and 0.53 BPM, respectively.

We note that the quantitative performance of the IR-based remote PPG system is comparable to an RGB-based camera system operating in steady daylight conditions [5]. The test results described above were collected with a limited number of people and in laboratory conditions. Nevertheless, we believe that the results are relevant. A larger population would mean more variability in skin type but it is known that the reflectance in the IR-domain is not heavily dependent on the skin type [11]. The current system is able to handle different geometries of subject and camera by adjusting lens settings (e.g. zooming). Within the automotive context, vibrations of the vehicle are presumably one of the larger challenges. In an RGB-based remote PPG set-up [12] we showed that small camera motions can be handled. Similar techniques can be also applied to IR-based remote PPG sensing.

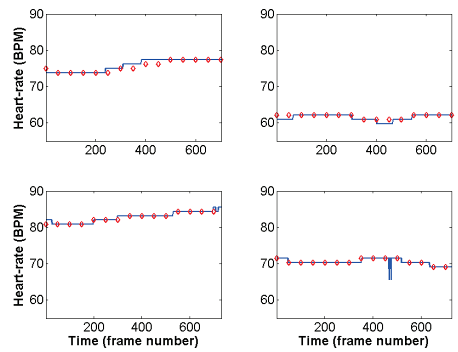

Fig. 2. Heart-rate values of IR-based remote PPG measurement (continuous line - blue) and reference measurement (diamond shapes - red) for four subjects.

V. Conclusion

The proposed IR-based remote PPG system shows that robust camera-based heart rate measurement is feasible in highly dynamic light conditions. Even during the most difficult lighting conditions, i.e disco light, the RMSE reported is less than 1 BPM with a maximum error of 5.8 BPM, and the correlation with reference measurements is above 0.99. The obtained results make the IR-based remote PPG technology an interesting candidate for automotive applications. Future research may be to validate these results over a larger population in real driving conditions.

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