High-resolution motion-compensated imaging photoplethysmography for remote heart rate monitoring

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Presentation Outline

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Introduction

What is imaging photoplethysmography (PPG)?

- PPG: technique of optically acquiring a volumetric measure of an organ
- PPG is non-invasive, but typically requires physical contact
- Imaging PPG refers to the acquisition of a PPG measurement via video

Advantages of imaging PPG

- More sanitary
- Efficient
- More cost-effective

State-of-the-Art

The first imaging PPG systems to be developed [1, 2, 3] used active illumination via LED arrays to acquire PPG signals.

More recently, state-of-art imaging PPG techniques focus on extracting heart rate from videos using ambient light [4, 5].

- However, these techniques tend to be inconsistent and sensitive to noise

A consistent and robust method that is biologically motivated is desirable.

We present a novel, biologically-inspired method for remote heart rate monitoring via motion-compensation skin erythema fluctuation analysis.

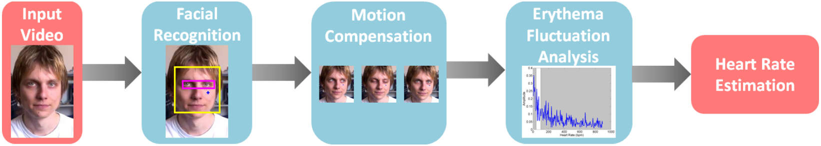

Figure: Proposed framework for motion compensated non-contact PPG imaging system.

Why skin erythema?

- Skin erythema is the redness of skin caused by hyperemia of superficial capillaries.
- Skin erythema has an excellent linearity with hemoglobin concentration [6].

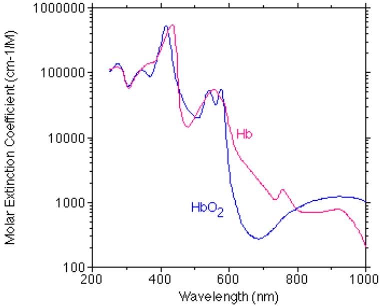

Figure: Absorption estimation of Hb and HbO_2 across the visible spectrum.

- Thus, it can be used to measure a subject's blood flow and extract a heart rate estimation.

Motion compensation via point tracking is used to make the acquisition of biometric signals from video more robust to temporal noise (e.g., natural human motion, and lighting fluctuations).

$$\underline{x}_t = f(\underline{x}_{t-1}) \tag{1}$$

To eliminate large variations caused by point noise, the sample was expanded to an $n \times n$ pixel window centred at location $\underline{x}_t$.

Thus, at a given time t

$$r(t) = \mathrm{E}(r|\Omega(\underline{x}_t)) \qquad g(t) = \mathrm{E}(g|\Omega(\underline{x}_t)) \tag{2}$$

subject to

$$r(t_0) = \mathrm{E}(r|\Omega(\underline{x}_0)) \qquad g(t_0) = \mathrm{E}(g|\Omega(\underline{x}_0)) \tag{3}$$

The Viola-Jones algorithm [7] is used to register the subject's face and sub-features (i.e., eyes, mouth, and nose), and the initial sample location $\underline{x}_0$ is determined with respect to the sub-features.

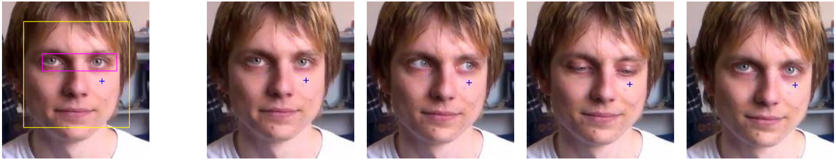

Figure: Facial recognition [7] and tracking [8] of selected sample point (denoted by blue "+").

- $\underline{x}_0$ is selected to be on the subject's upper cheek based on facial skin thickness [9] and flatness of the area.

Time series representation of skin erythema:

$$e(t) = \log_{10} \frac{1}{g(t)} - \log_{10} \frac{1}{r(t)} \tag{4}$$

Given $e(t)$, the frequency representation of the erythema signal $E(u) = \mathcal{F}\{e(t)\}$ can be used to determine an estimation of the subject's heart rate in the video:

$$u_{\mathrm{HR}} = \arg\max_{u} \; |E(u)| \qquad \text{subject to} \qquad \alpha \leq H(u) \leq \beta \tag{5}$$

where $H(u) = 60u$ is a function for converting frequency (Hz) to heart rate (bpm).

The average resting heart rate is between 60 bpm and 100 bpm [10].

- Lower limit α is set to 40 bpm
- Upper limit β is set to 100 bpm

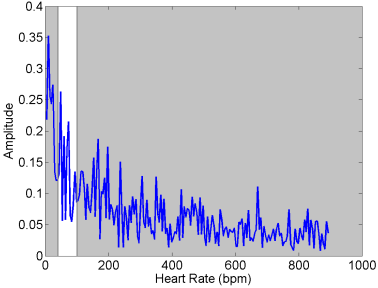

Figure: Range of considered frequencies during erythema fluctuation analysis.

The subject's estimated HR is

$$HR = H(u_{HR}) \tag{6}$$

- All videos used for testing feature a single front-facing subject in natural ambient light, and were recorded in 1080p at 30fps using a static mobile phone (HTC One S)

- Heart rate measurements were recorded using The Easy Pulse (a HRM-2511E sensor)
- Erythema fluctuation analysis (EFA) was compared to Eulerian Video Magnification (EVM) [4] and Independent Component Analysis (ICA) [5] using the set test videos.

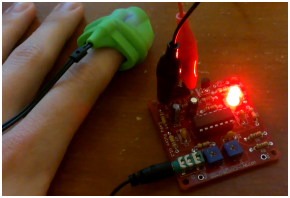

Figure: The Easy Pulse sensor recording heart rate measurements.

Table: Comparison of percentage errors for subjects at rest for proposed EFA method, EVM [4], and ICA [5]. The proposed method has the lowest mean percentage error and standard deviation (std).

Algorithm	**Percentage Error (mean $\pm$ std)**
EFA	$\mathbf{12.1 \pm 10.6}$
EVM [4]	28.9 ± 16.6
ICA [5]	20.0 ± 17.3

T-test significance:

- EVM and ICA: p-value of 31.2%
- EVM and EFA: p-value of 3.3%

Discussion

We presented a novel motion-compensated erythema fluctuation-based method for remote heart rate monitoring

- Experimental results indicate that the proposed method (EFA) performs significantly better than state-of-art methods

Future works:

- Further testing (subjects in different lighting conditions)
- More robust and dynamic sampling methods
- EFA for other cardiovascular metrics

Acknowledgements

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Thank you
Questions?