Contact Surface Area: A Novel Signal for Heart Rate Estimation in Smartphone Videos

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Motivation

A need exists for **accurate heart rate measurement** for health and fitness tracking.

**Smartphones are ubiquitous** and portable, so they are a natural platform for heart rate measurement.
State of the Art: Photoplethysmography (PPG)

Finger Position
Place the tip of your index finger gently on the inner camera lens

Instant Heart Rate by Azumio

Morpholio

78 BPM (Beats Per Minute)
State of the Art: Photoplethysmography (PPG)

Finger Position
Place the tip of your index finger gently on the inner camera lens

The most accurate PPG apps:
- |error| > 10 bpm on > 6% of videos
- |error| > 20 bpm on > 4% of videos

[Coppetti 2017]
Our Contribution

We augment PPG using **contact surface area** from smartphone fingertip videos.

Our experiments show that this **reduces the occurrence of substantial heart rate estimation errors**.
Our Contribution: Contact Surface Area Model
Our Contribution: Contact Surface Area Model

Recording Setup

Unprocessed Video

Estimated Contact Surface Area (Ellipse)

\[ \text{area} = \frac{\text{force}}{\text{pressure}} \]
Heart Rate Estimation

\[ HR = \frac{\sigma^2_p}{\sigma_p^2 + \sigma_L^2} HR_F + \frac{\sigma^2_F}{\sigma_p^2 + \sigma_L^2} HR_L \]
Heart Rate Estimation

\[
HR = \frac{\sigma_F^2}{\sigma_F^2 + \sigma_L^2} HR_F + \frac{\sigma_L^2}{\sigma_F^2 + \sigma_L^2} HR_L
\]

[Otsu 1979, Fitzgibbon 1996]
Heart Rate Estimation

PPG and Area Frequency Spectra

Ensemble Heart Rate (MMSE)

\[ HR = \frac{\sigma_F^2}{\sigma_L^2 + \sigma_F^2} HR_F + \frac{\sigma_F^2}{\sigma_L^2 + \sigma_F^2} HR_L \]
Heart Rate Estimation

\[ \text{HR} = \frac{\sigma_F^2}{\sigma_F^2 + \sigma_L^2} \text{HR}_F + \frac{\sigma_F^2}{\sigma_F^2 + \sigma_L^2} \text{HR}_L \]

Ensemble Heart Rate (MMSE)

\( \sigma_F^2 \) and \( \sigma_L^2 \) were computed on training data (50%)
Procedure: Data Collection

- 62 participants
  - 37 female, 25 male
  - 786 videos (~13 each)

- Ages 18 - 64
  - 30.2 ± 15.4 years (females)
  - 27.2 ± 12.9 years (males)

- Heart rates: 77.1 ± 13.9 bpm
Consistency Results: Bland-Altman

PPG-only

PPG-area

HR Error (bpm)

HR Average w/ Ground Truth (bpm)
## Estimation Accuracy

<table>
<thead>
<tr>
<th></th>
<th>PPG-only</th>
<th>PPG-area</th>
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<tbody>
<tr>
<td>Videos accepted (%)</td>
<td>93.5</td>
<td>91.25</td>
</tr>
<tr>
<td>Mean abs. testing error ± std.</td>
<td>2.91 ± 0.29</td>
<td>2.60 ± 0.21</td>
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<td>error (bpm)</td>
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<td>error &gt; 20 bpm (%)</td>
<td>2.67</td>
<td>1.10</td>
</tr>
<tr>
<td>Videos with abs. testing error</td>
<td></td>
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</tr>
<tr>
<td>error &gt; 40 bpm (%)</td>
<td>0.53</td>
<td>0.00</td>
</tr>
<tr>
<td>Pearson’s $r$ (p &lt; 0.00001)</td>
<td>0.89 (n = 374)</td>
<td>0.94 (n = 365)</td>
</tr>
<tr>
<td>Mean bias (bpm)</td>
<td>-0.84</td>
<td>-0.51</td>
</tr>
<tr>
<td>95% limits of agreement</td>
<td>(-13.27, 11.59)</td>
<td>(-9.71, 8.69)</td>
</tr>
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<td>with arm cuff (bpm)</td>
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PPG-only ~matches the error rates of commercial apps, and PPG-area has substantially lower error rates.
Conclusions and Future Work

Our contribution: We augment PPG using contact surface area from smartphone fingertip videos. Our experiments show that this reduces the occurrence of substantial heart rate estimation errors.

Future work: PPG-area could enable smartphone estimation of blood pressure and hematocrit.

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github.io/sarafridov/FingertipVideo
Acknowledgments

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• Study participants