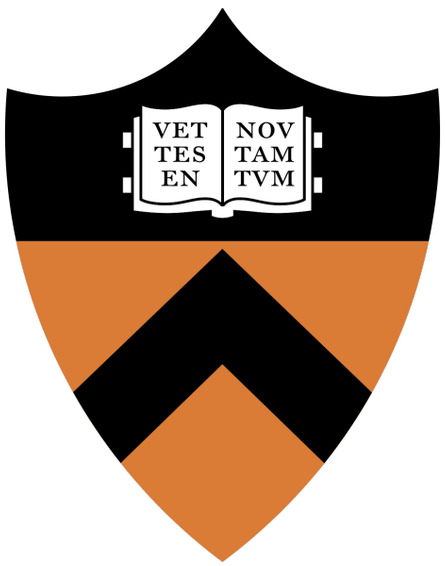
Contact Surface Area: A Novel Signal for Heart Rate Estimation in Smartphone Videos

Sara Fridovich-Keil and Peter J. Ramadge
Princeton University



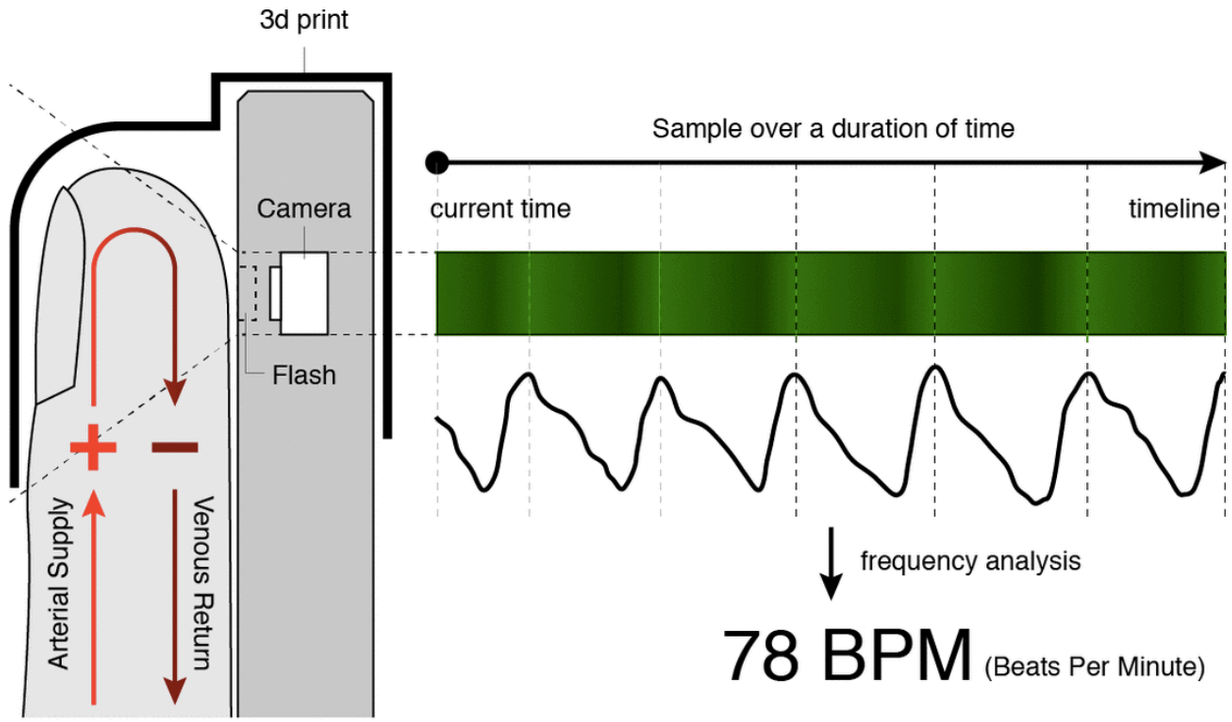
Motivation

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.

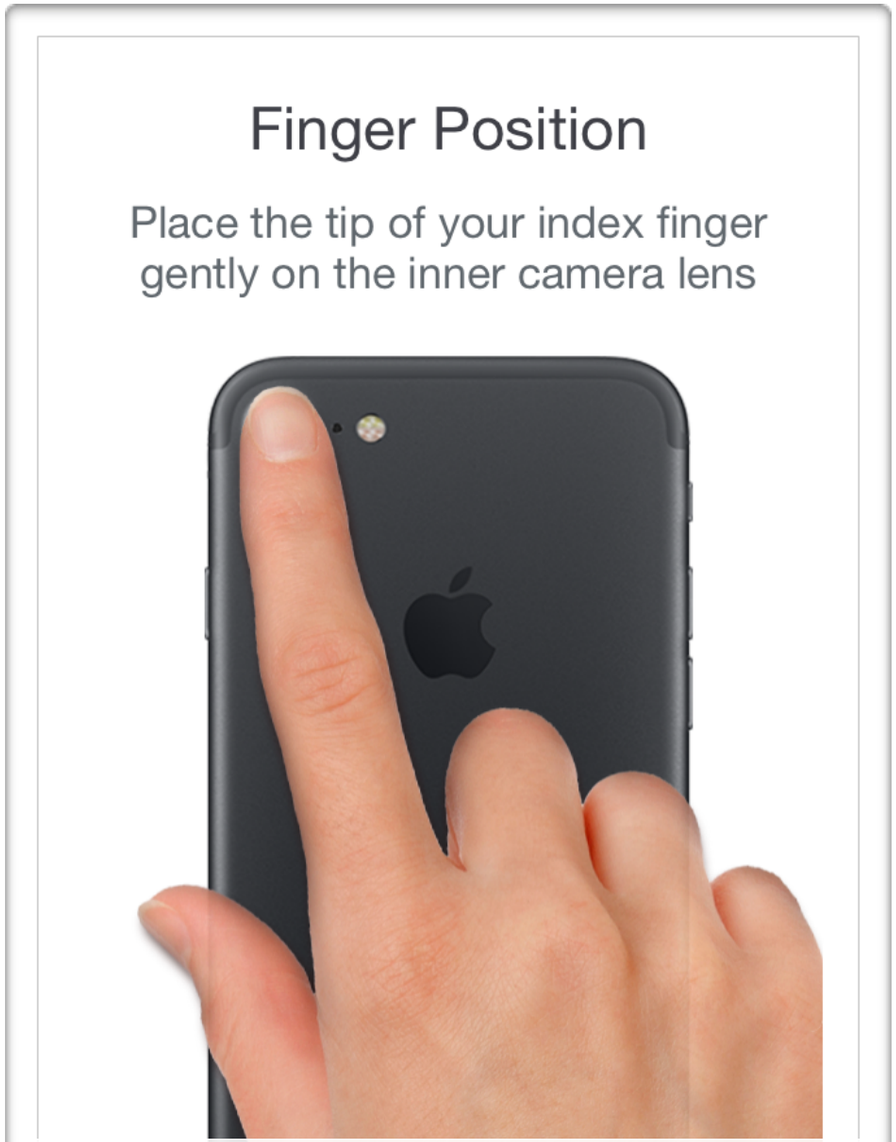
State of the Art: Photoplethysmography (PPG)

Instant Heart Rate by Azumio

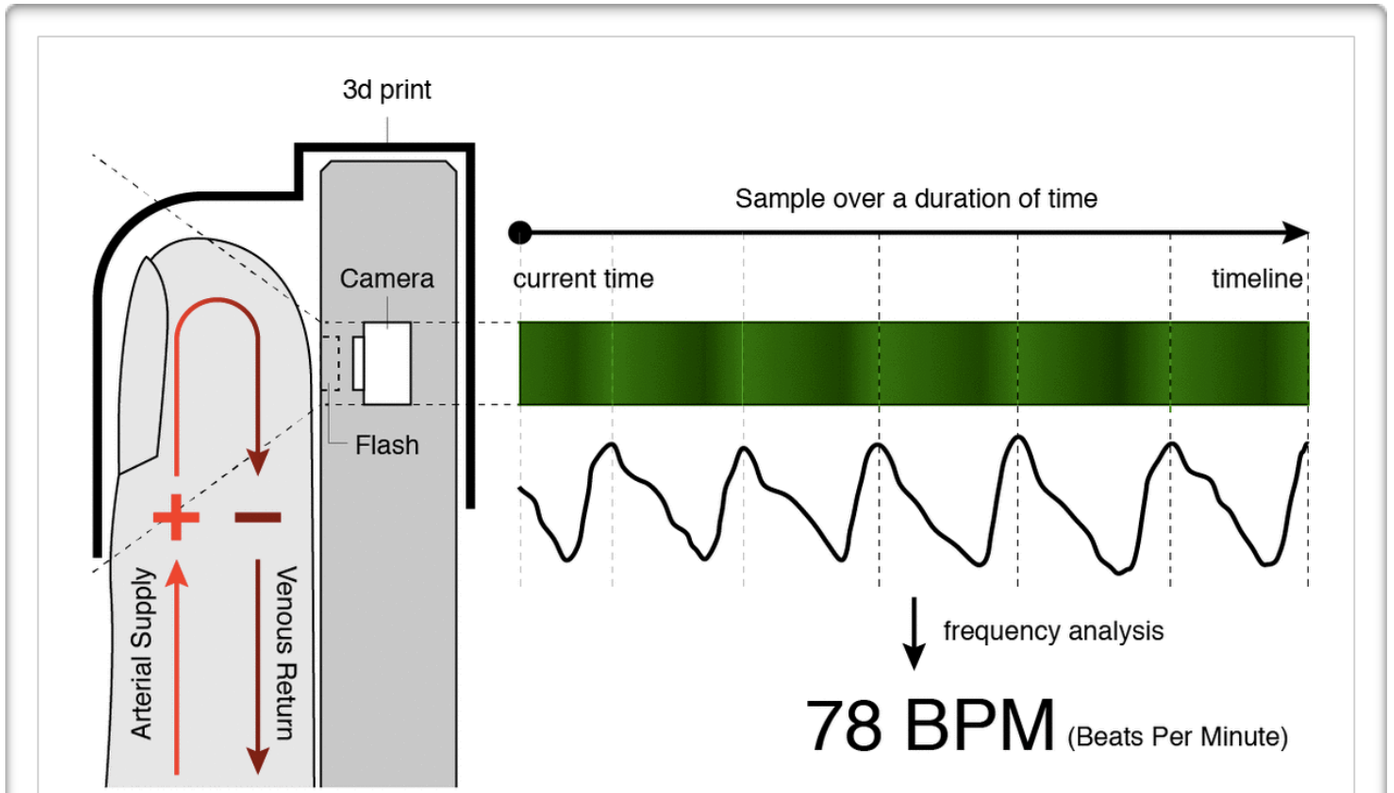


Morpholio

State of the Art: Photoplethysmography (PPG)



Instant Heart Rate by Azumio



Morpholio

The most accurate PPG apps:

- |error| **> 10 bpm** on **> 6%** of videos
- |error| **> 20 bpm** on **> 4%** of videos

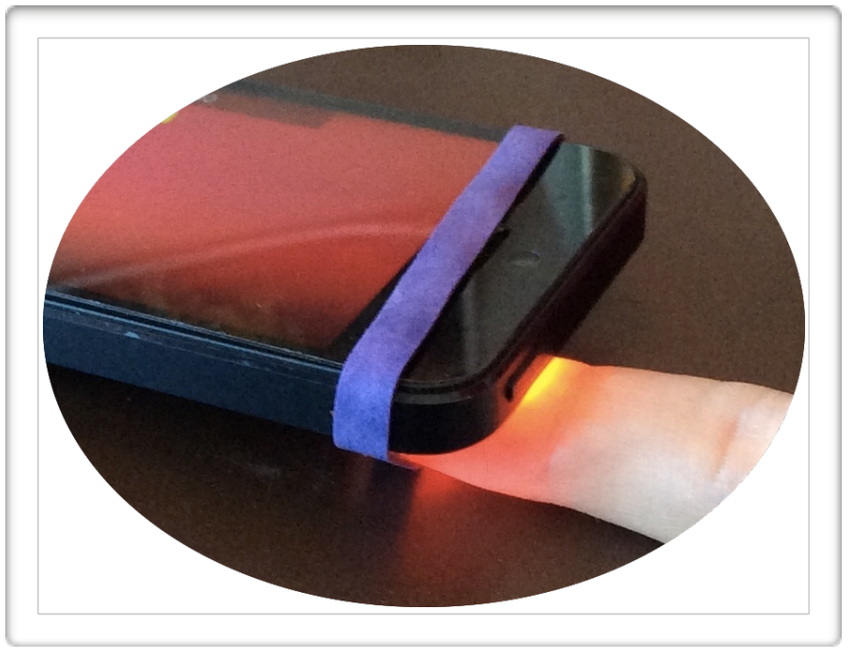
[Coppetti 2017]

Our Contribution

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

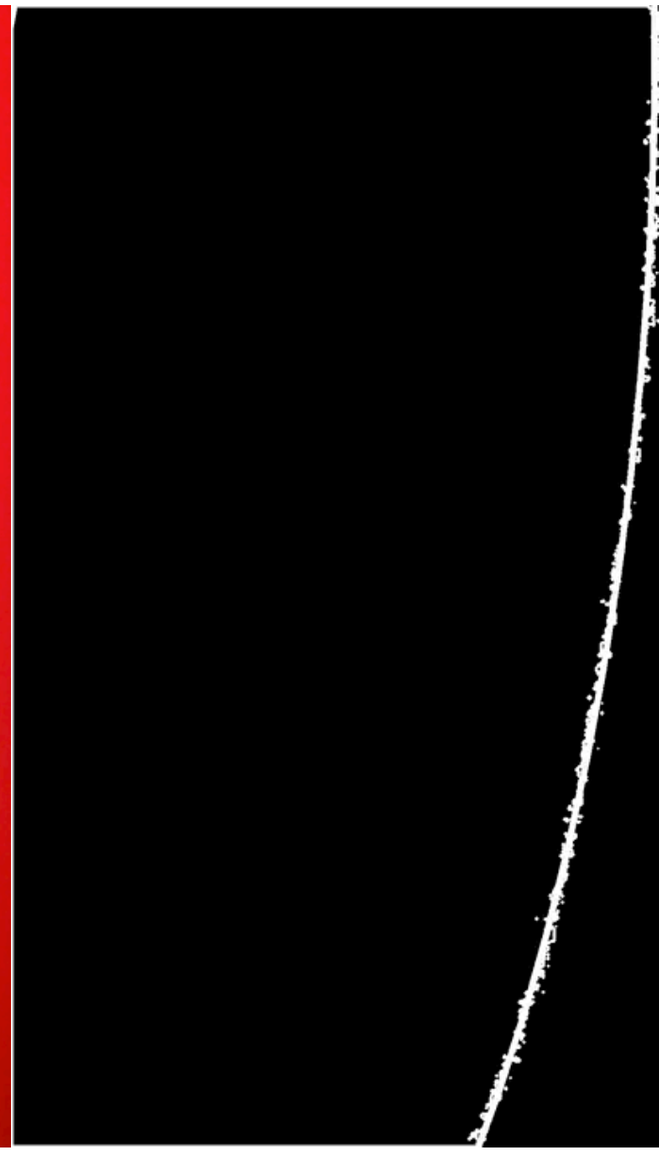
Our experiments show that this **reduces the occurrence of substantial heart rate estimation errors**.

Our Contribution:
Contact Surface Area Model



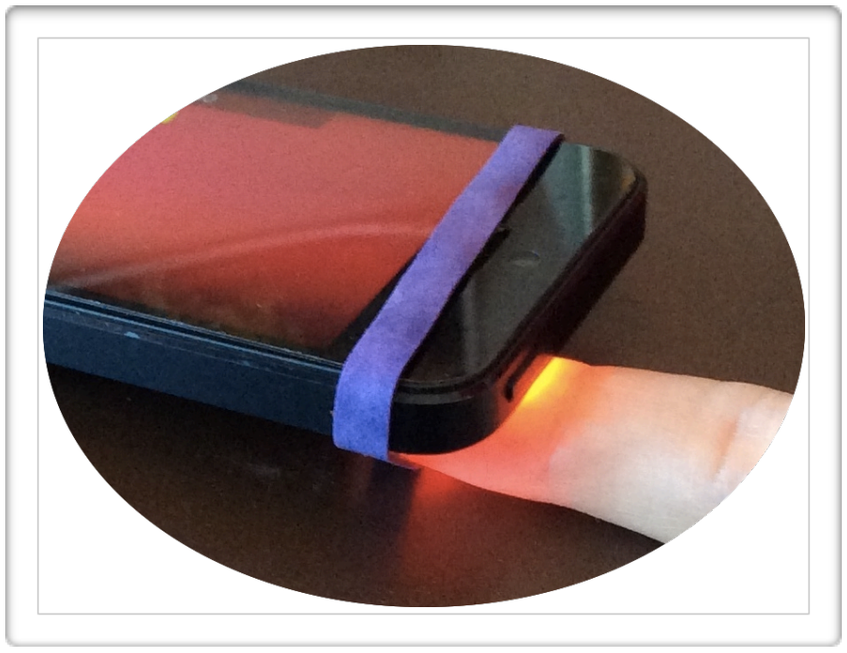
Recording Setup

Unprocessed Video



Estimated Contact Surface Area (Ellipse)

Our Contribution: Contact Surface Area Model



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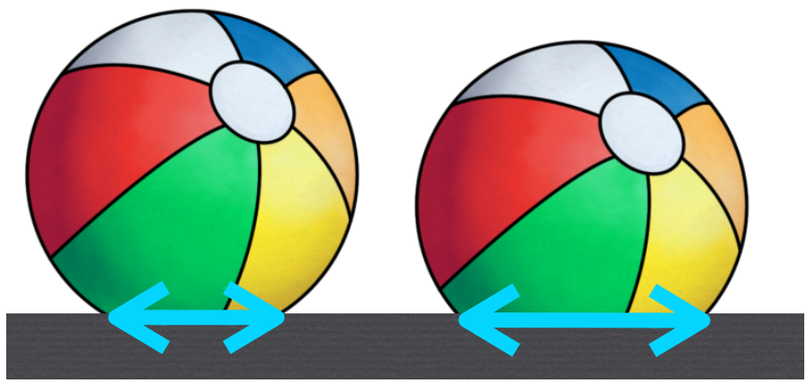
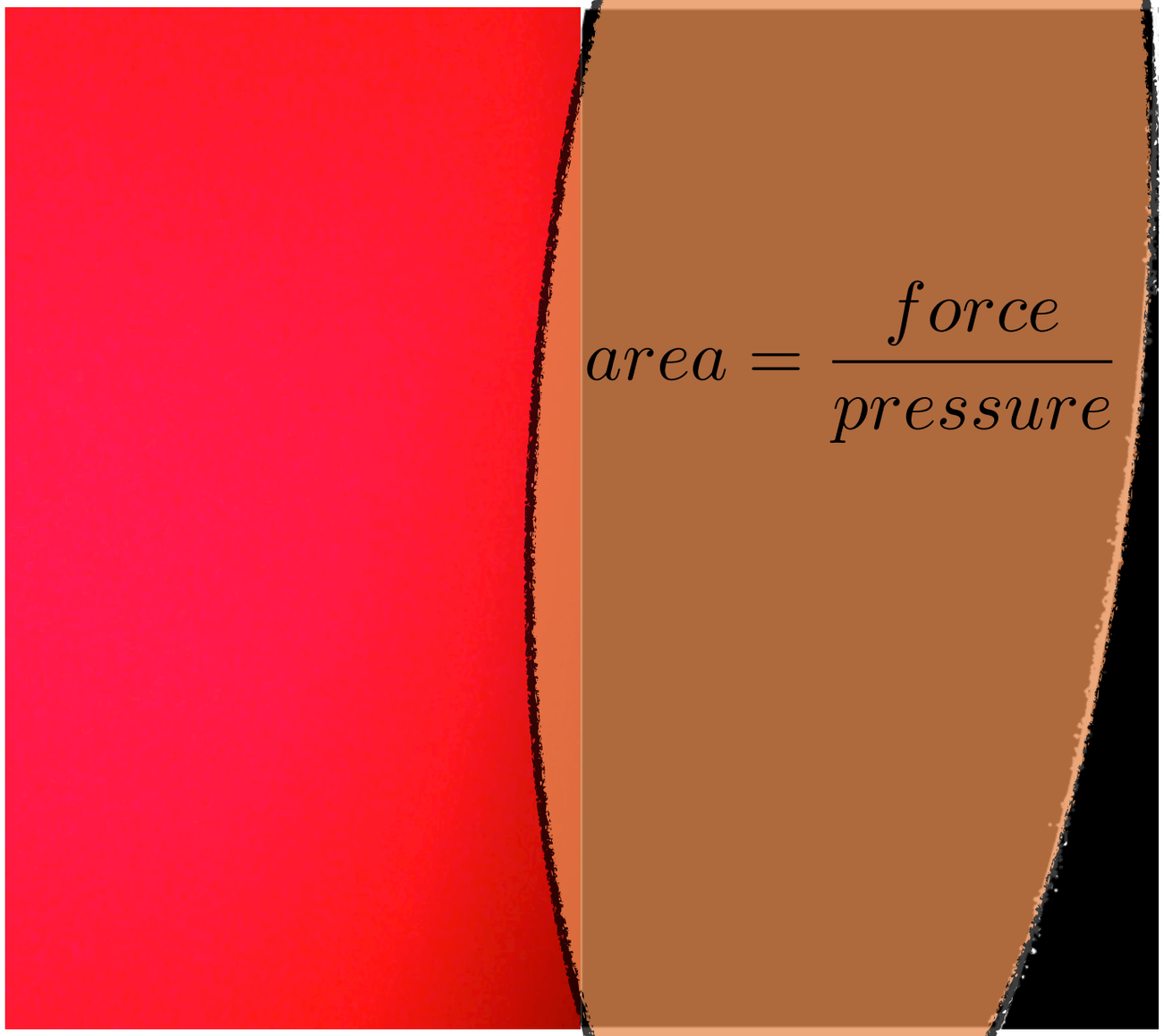


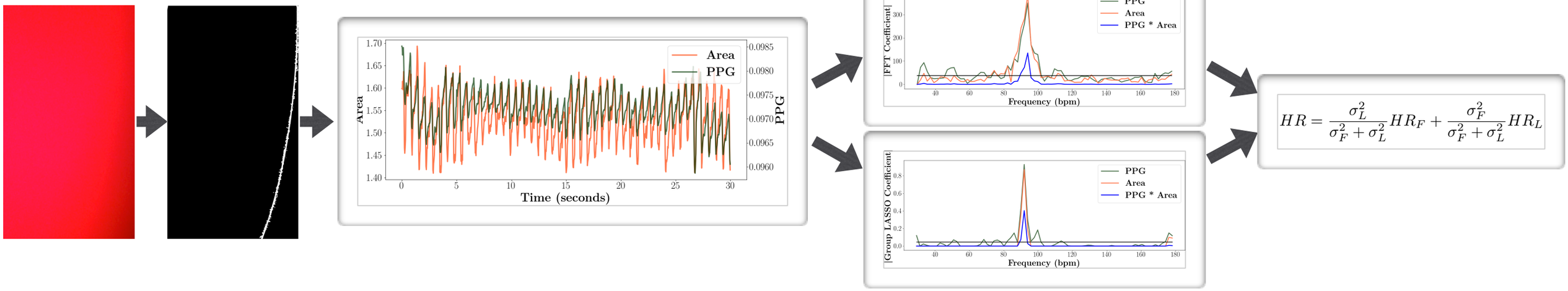


Unprocessed Video

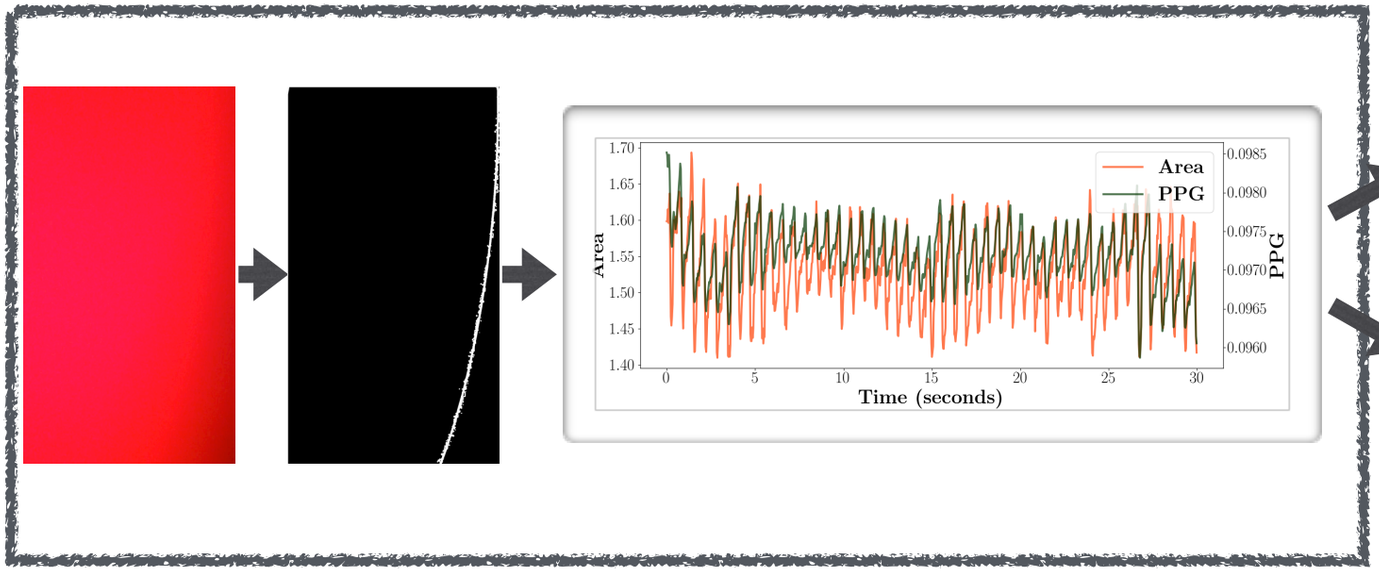
$$area = \frac{force}{pressure}$$

Estimated Contact Surface Area (Ellipse)

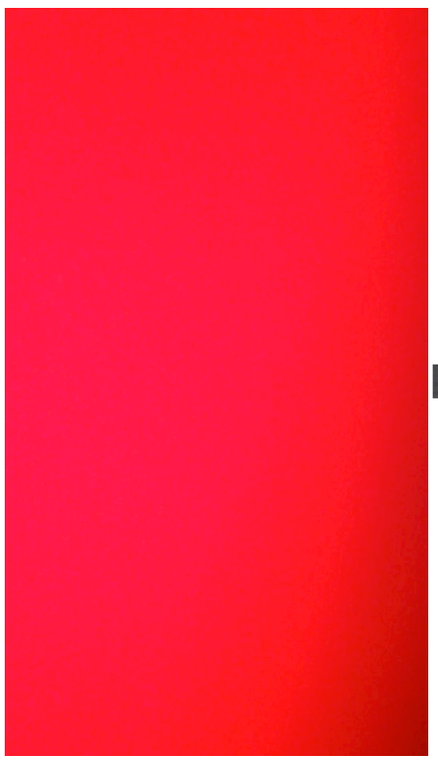
Heart Rate Estimation



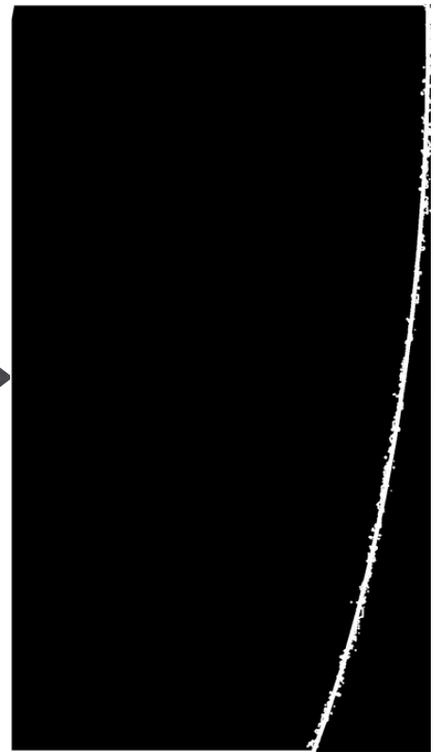
Heart Rate Estimation



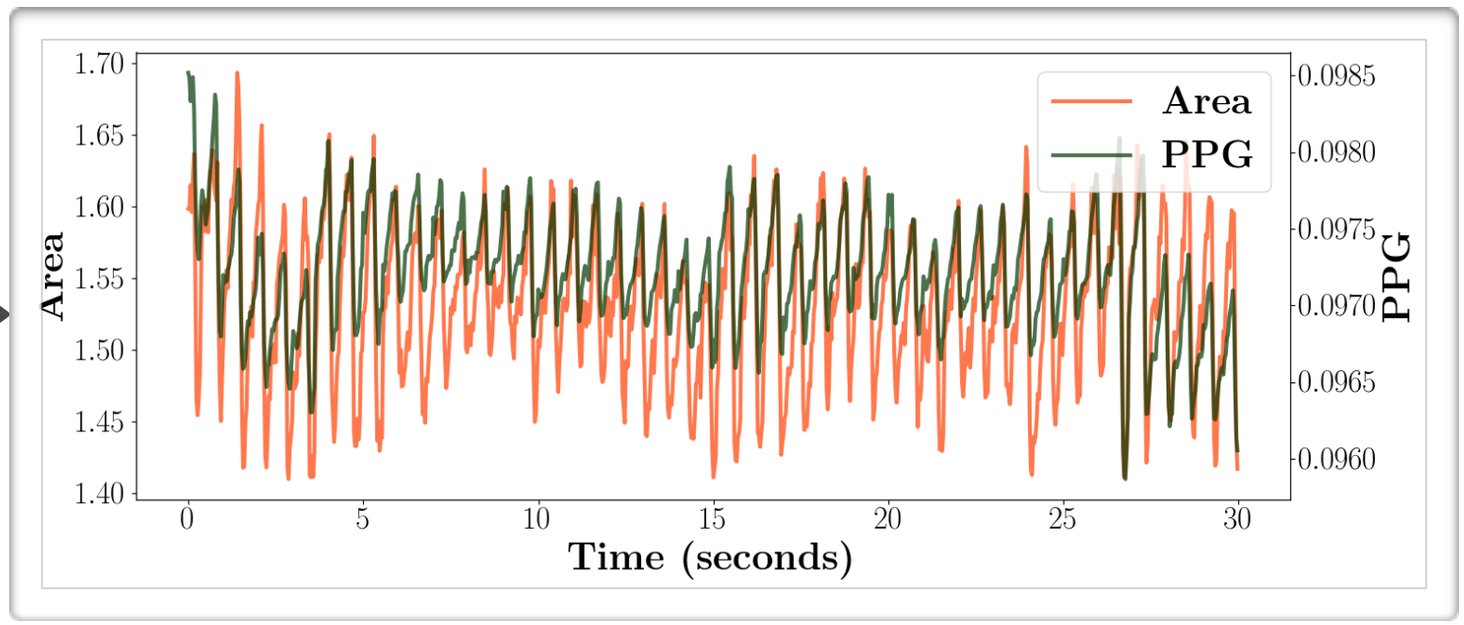
$$HR = \frac{\sigma_L^2}{\sigma_F^2 + \sigma_L^2} HR_F + \frac{\sigma_F^2}{\sigma_F^2 + \sigma_L^2} HR_L$$



Unprocessed Video



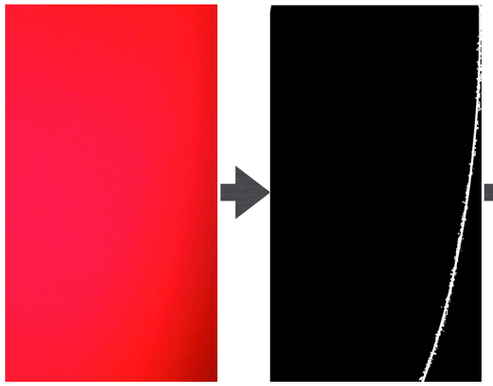
Estimated Ellipse

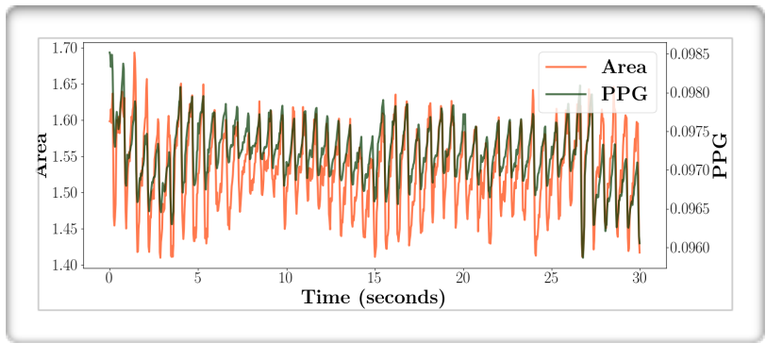


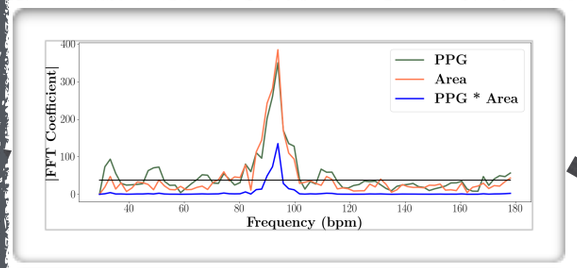
PPG and Area Time Series

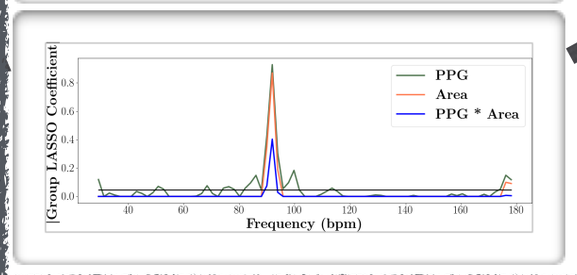
[Otsu 1979, Fitzgibbon 1996]

Heart Rate Estimation









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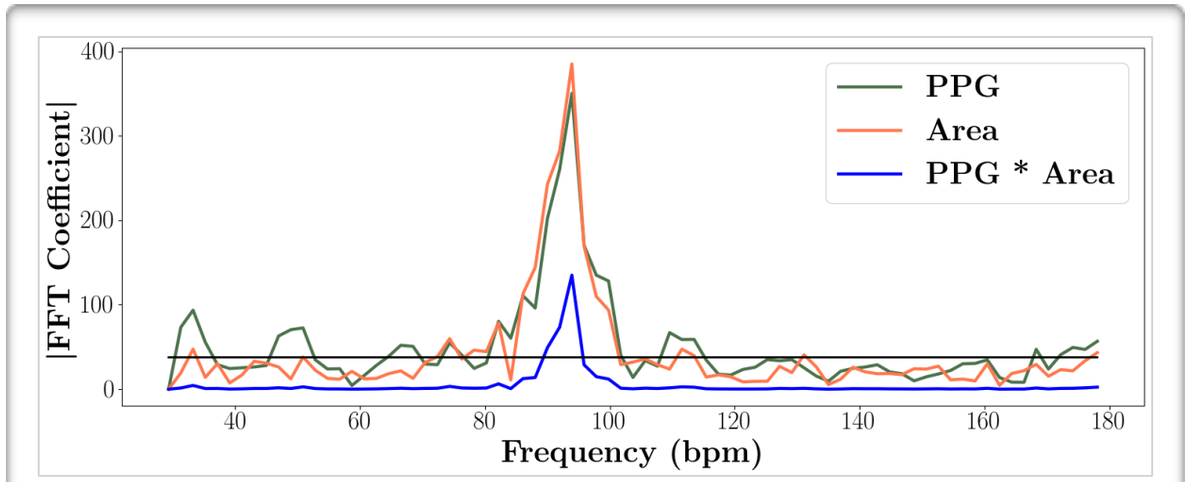
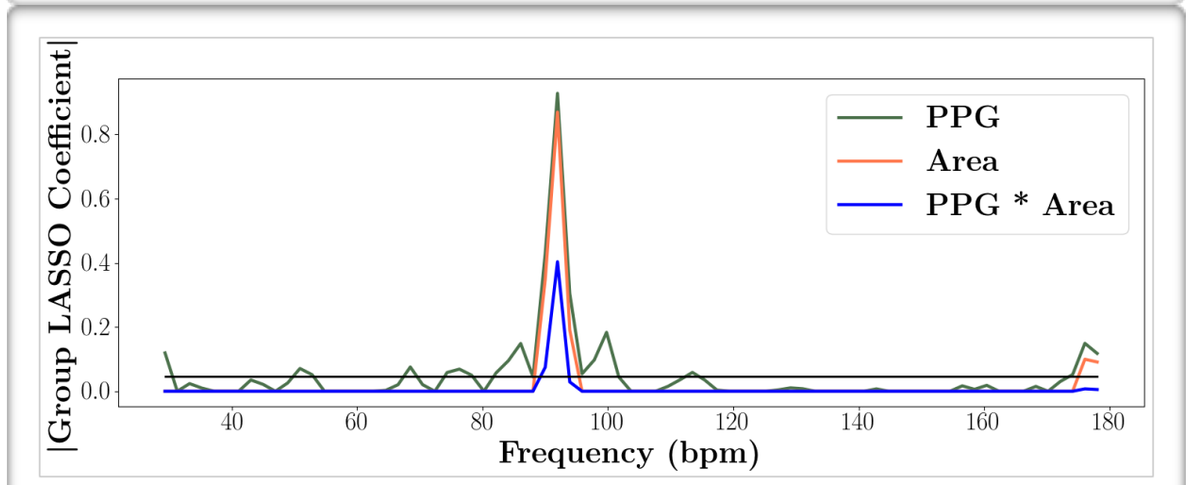


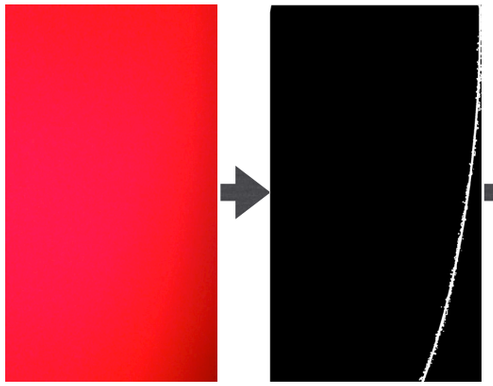


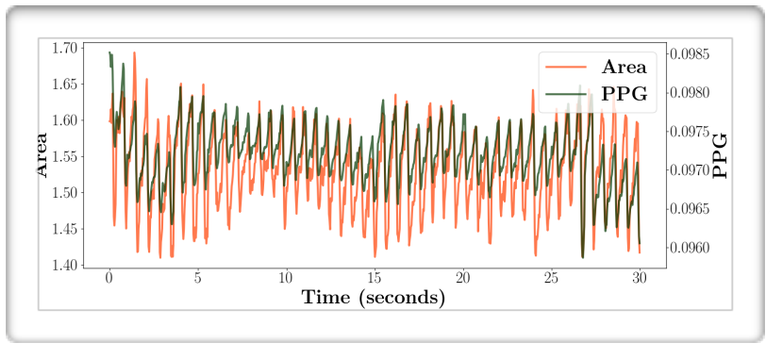
PPG and Area Frequency Spectra

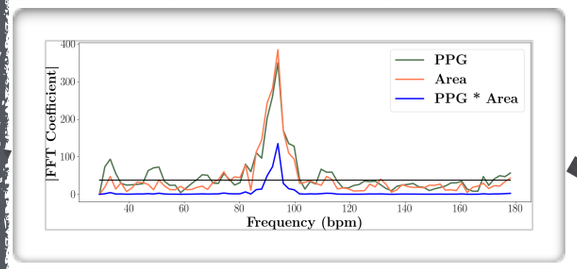
$$HR = \frac{\sigma_L^2}{\sigma_F^2 + \sigma_L^2} HR_F + \frac{\sigma_F^2}{\sigma_F^2 + \sigma_L^2} HR_L$$

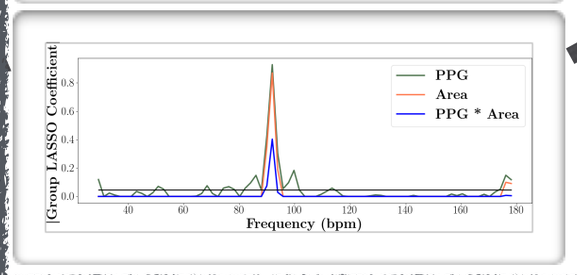
Ensemble Heart Rate (MMSE)

Heart Rate Estimation









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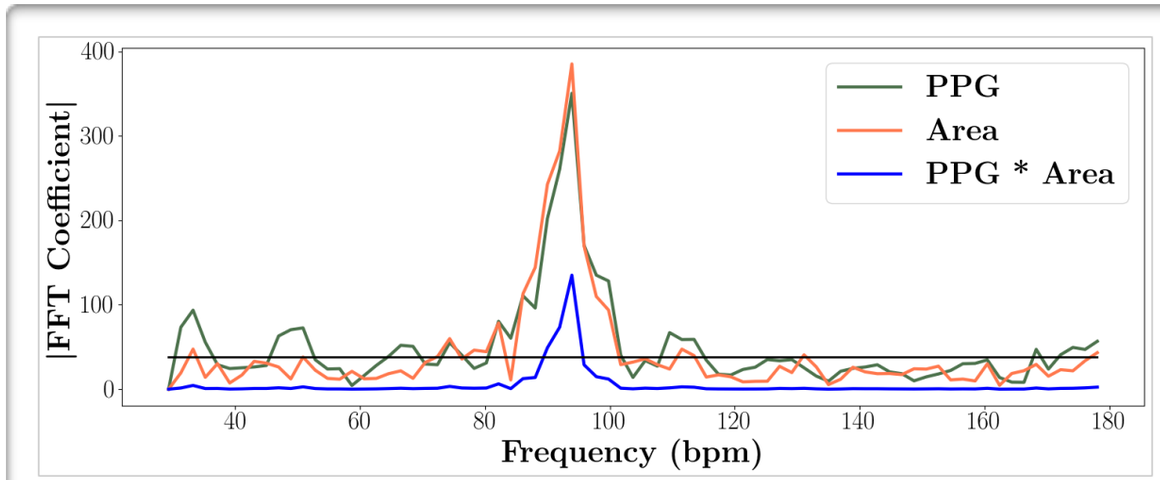

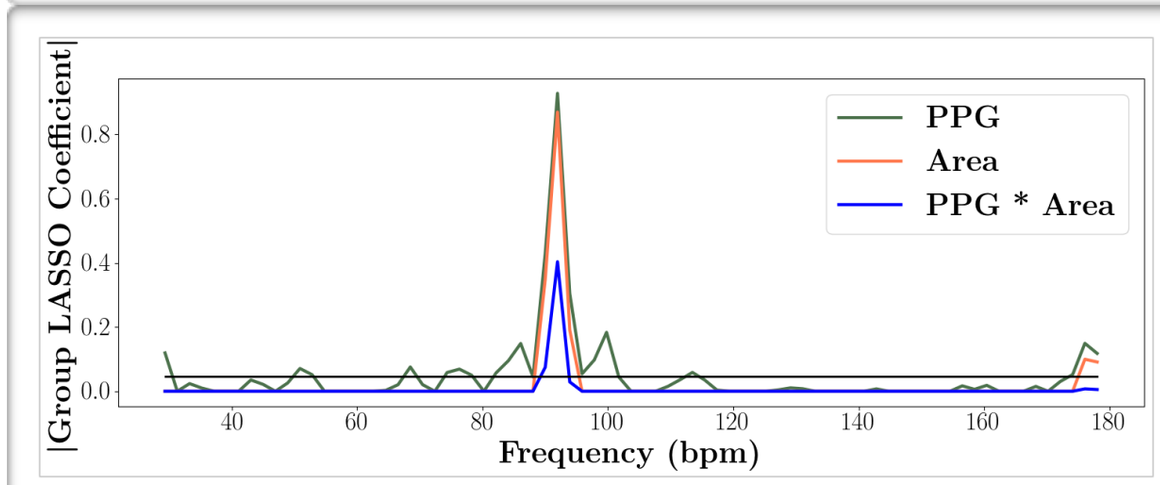

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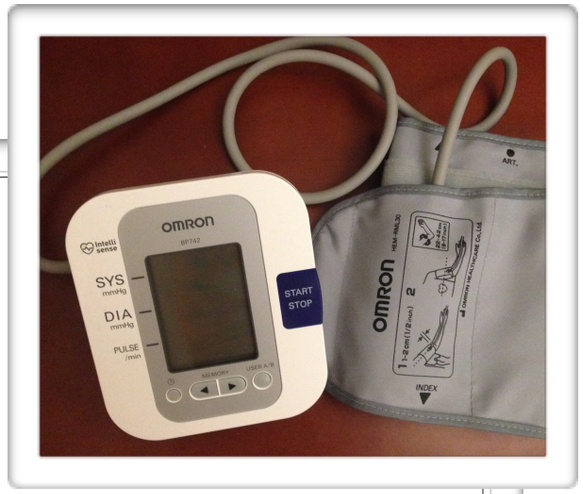
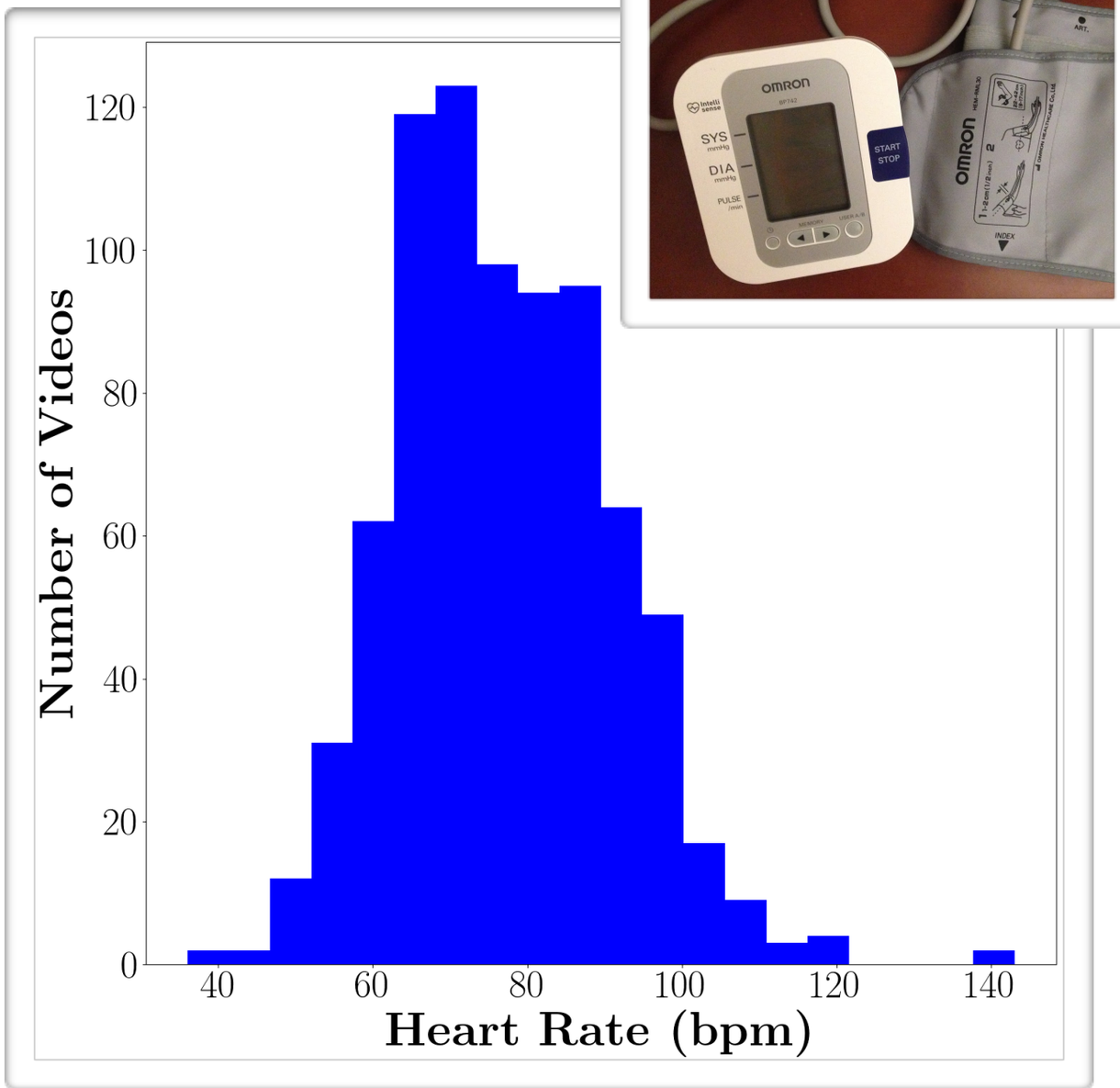
Ensemble Heart Rate (MMSE)

σ_F^2 and σ_L^2 were computed on training data (50%)

Procedure: Data Collection

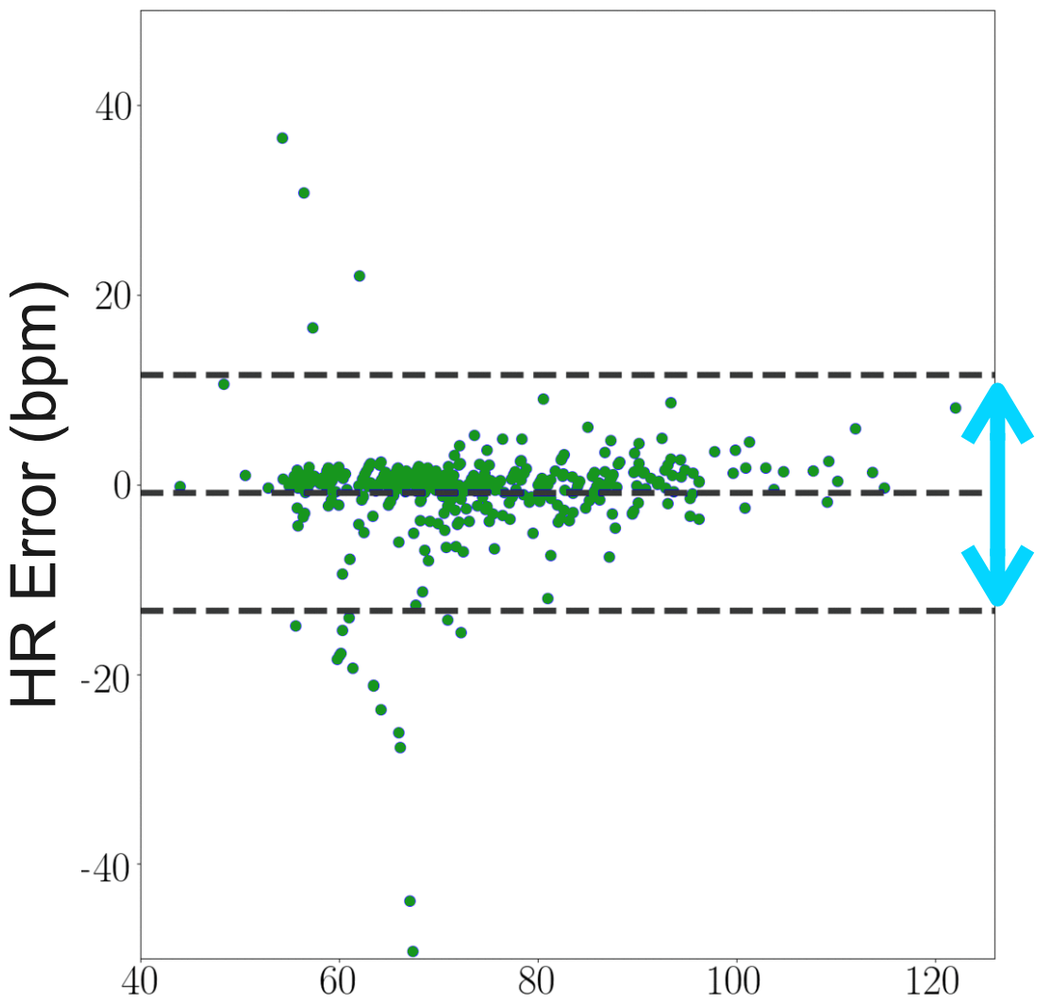
- 62 participants
  - 37 female, 25 male
  - 786 videos (~13 each)
- Ages 18 - 64
  - 30.2 ±15.4 years (females)
  - 27.2 ±12.9 years (males)
- Heart rates: 77.1±13.9 bpm



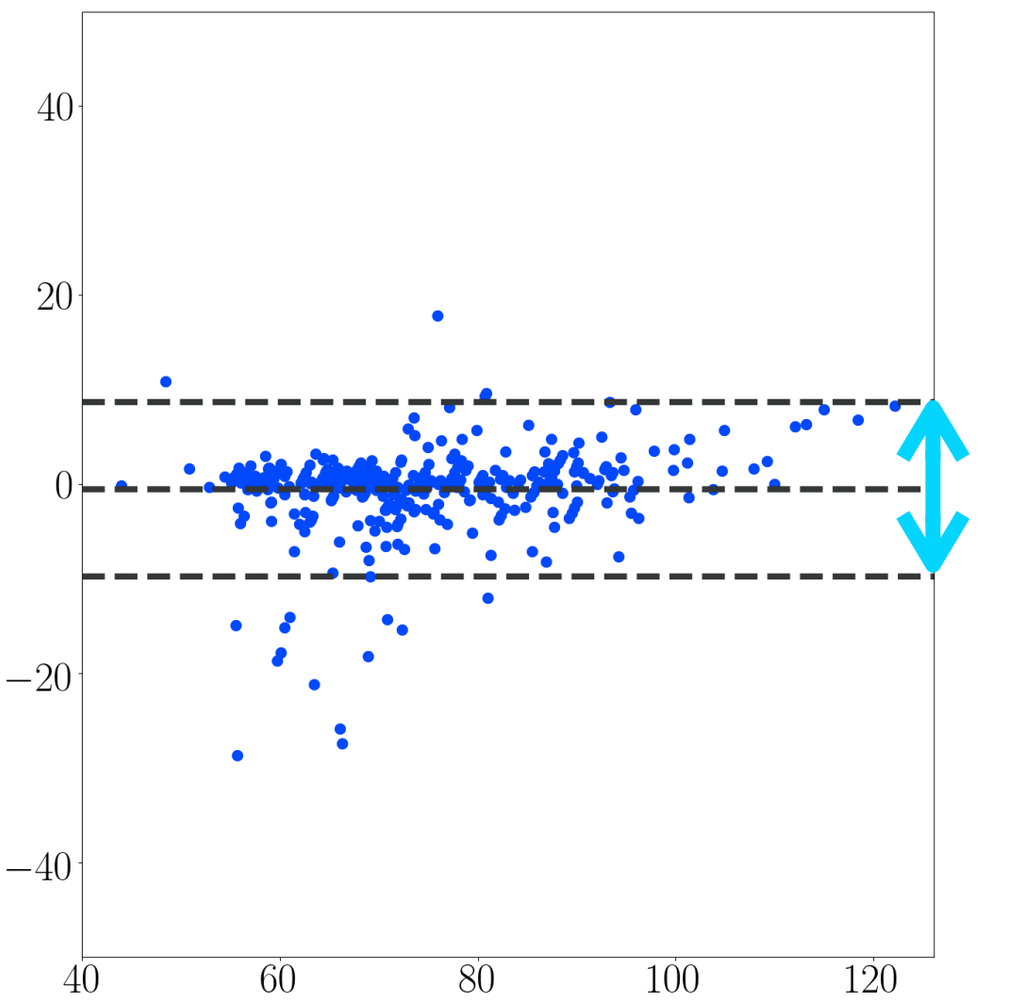


Consistency Results: Bland-Altman

PPG-only



PPG-area



Estimation Accuracy

	PPG-only	PPG-area
Videos accepted (%)	**93.5**	91.25
Mean abs. testing error ± standard error (bpm)	2.91 ± 0.29	**2.60 ± 0.21**
Videos with abs. testing error > 10 bpm (%)	6.42	**4.11**
Videos with abs. testing error > 20 bpm (%)	2.67	**1.10**
Videos with abs. testing error > 40 bpm (%)	0.53	**0.00**
Pearson's r ($p < 0.00001$)	0.89 ($n = 374$)	**0.94** ($n = 365$)
Mean bias (bpm)	-0.84	**-0.51**
95% limits of agreement with arm cuff (bpm)	(-13.27, 11.59)	**(-9.71, 8.69)**

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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**.

sfk@berkeley.edu

github.io/sarafridov/FingertipVideo

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PRINCETON

PRINCETON
Electrical Engineering

BAIR
BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

- Study participants