Short-term HRV using acceleration PPG under severe ambient settings using in-house developed wearable

WINTECHCON 2018

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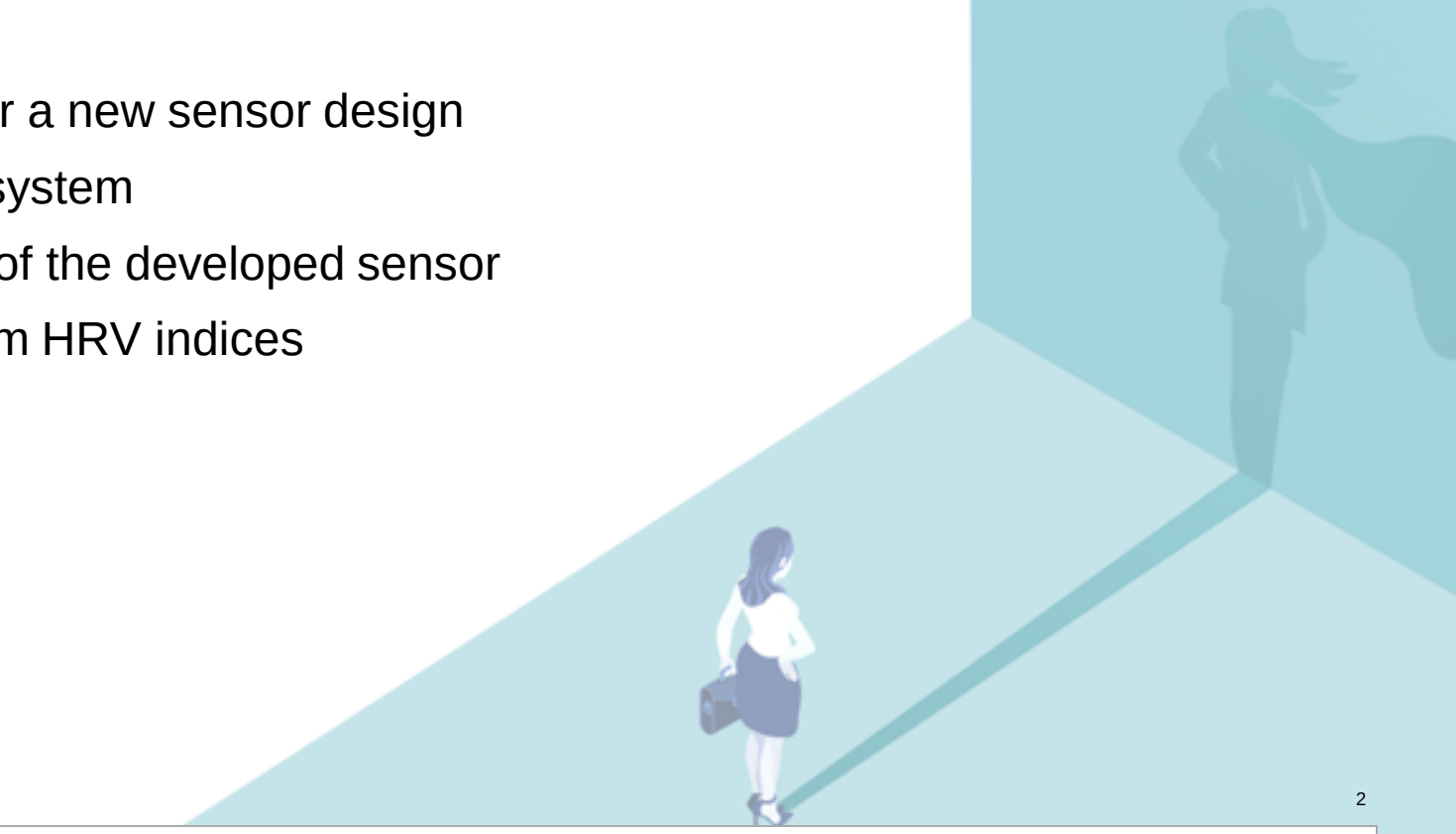
Agenda

- Heart Rate Variability (HRV) and its importance
- Need for measuring HRV from wearables
- Problem statement
- Theory of PPG and motivation for a new sensor design
- Overall design of measurement system
- Results to showcase advantage of the developed sensor
- Algorithm for extracting short-term HRV indices
- Experimental Results
- Conclusion and future scope



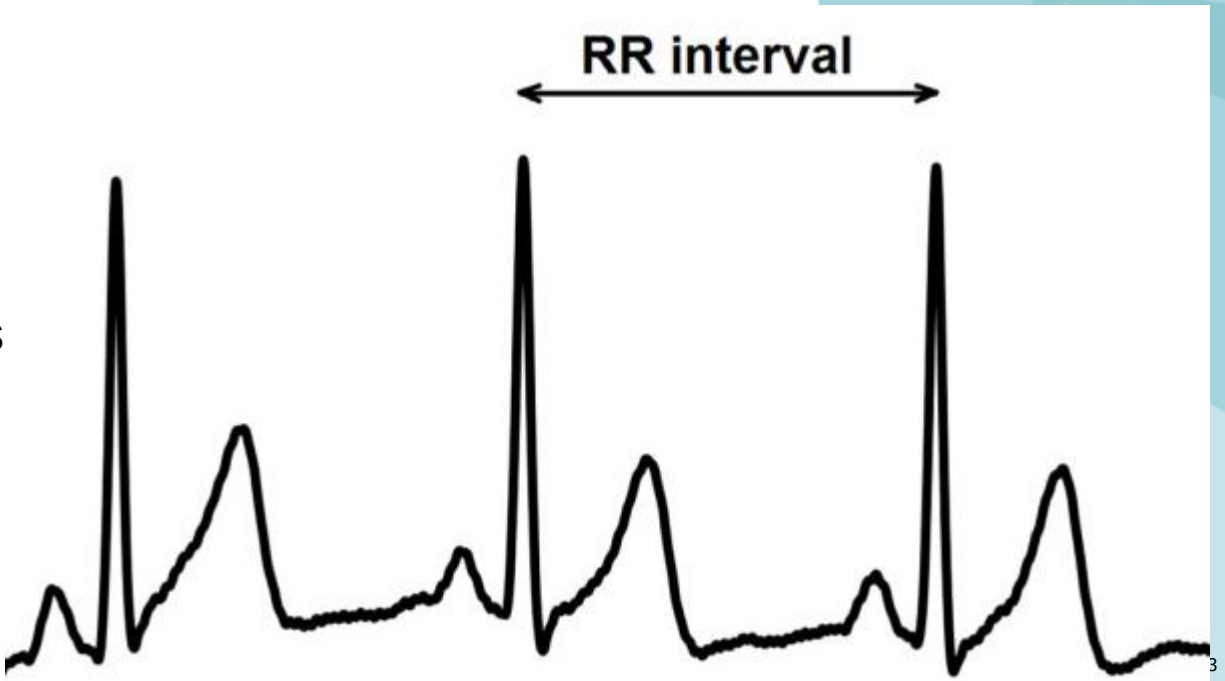
Heart Rate Variability

- The cardiac cycles of a healthy human heart are not constant.
- This variation in the subsequent cardiac cycles is referred to **Heart Rate Variability (HRV).**
- The gold-standard is to extract the variability information from the RR-intervals in ECG.
- Measurement of 24-hour HRV is not always feasible, hence, use of short-term .i.e. 5 minute HRV.

Importance of HRV

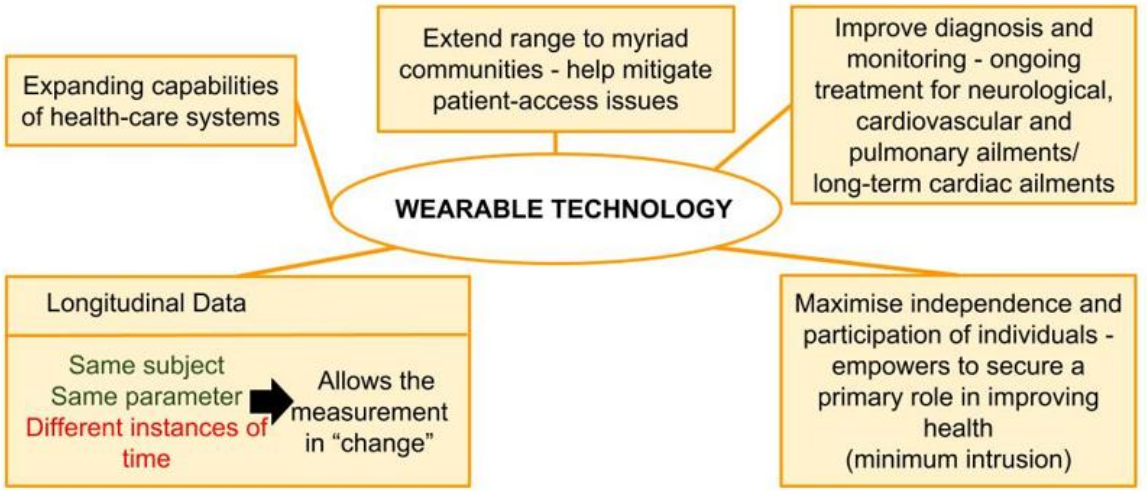
- HRV determines the energy, dynamism
- Underpins the ability to think clearly and
- HRV is important for well-being. Predicts

HRV is an important vital sign.



Measurement of HRV from wearables

- Paradigm shift to individual centered health-care from a hospital centered one.



- Such a shift undeniably has a positive outcome on patient-care front. Thus, compels innovative design and further research on wearable technology.
- Improve serviceability of wearable.
- Many derived signs like stress, long-term cardiac ailments etc. can be detected in advance.

Problem Statement

- Several works suggest surrogacy of ECG derived HRV to the ones derived from PPG[1].

From now on PPG derived HRV will be referred as PRV (Pulse Rate Variability) throughout the presentation.

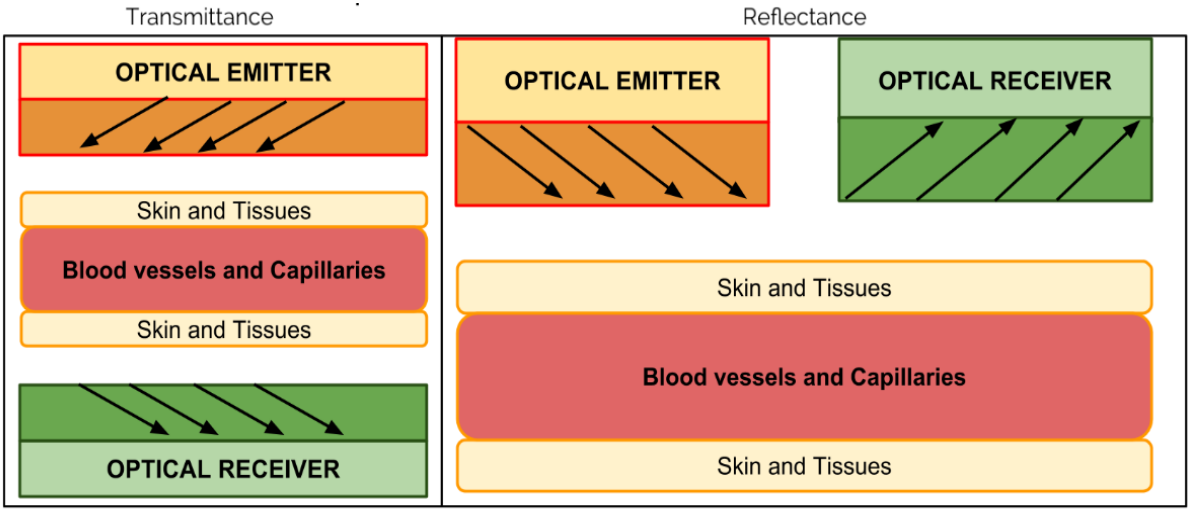
- Most studies show the agreement of PRV to HRV only from the extremities of body like fingers, ear-lobes[2] etc. using transmittance photoplethysmography (to be explained in later slides).
- Limited works show use of wrist-based reflective photoplethysmography as a reliable measure for HRV.

In the presented work the use of wrist based PPG as an alternate to ECG for HRV, is proposed.

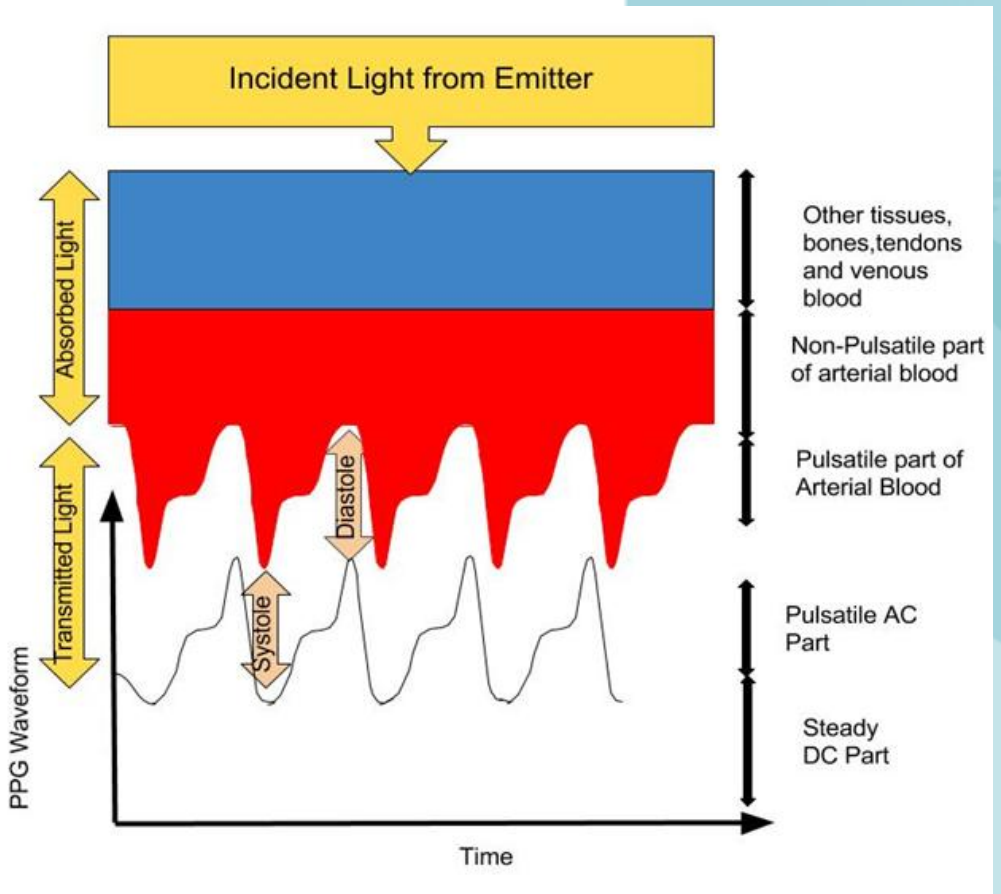
[1] M. Nitzan, A. Babchenko, B. Khanokh, and D. Landau, "The variability of the photoplethysmographic signal-a potential method for the valuation of the autonomic nervous system," *Physiological measurement*, vol. 19, no. 1, p. 93, 1998.
[2] F. Chang, C. Chang, C. Chiu, S. Hsu, and Y. Lin, "Variations of hrv analysis in different approaches," in *Computers in Cardiology, 2007*. IEEE, 2007, pp. 17–20.

Underlying principle of wearable cardiac monitors

Photoplethysmography (PPG)



Reflective Photoplethysmography

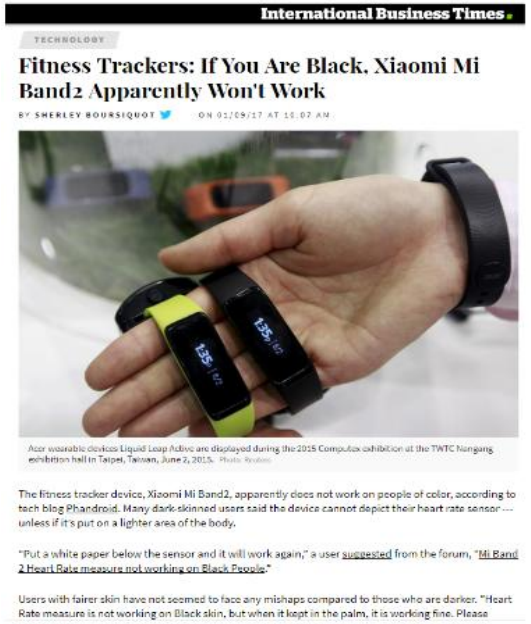


- Pulsatile component
- Steady component
- Optical signal transduced to electrical domain

Novel optical sensor scheme

State-of-the-art :

Most commercial devices use 495nm – 530 nm as optical emitters for HR wrist-based wearables. Low signal quality due to skin pigmentation are not addressed.



International Business Times

TECHNOLOGY

Fitness Trackers: If You Are Black, Xiaomi Mi Band2 Apparently Won't Work

BY SHERLEY BOURSIQUOT ON 01/09/17 AT 10.07 AM

Acer wearable devices Liquid Leap Active are displayed during the 2015 Computex exhibition at the TWTC Nangang exhibition hall in Taipei, Taiwan, June 2, 2015. Photo: Reuters

The fitness tracker device, Xiaomi Mi Band2, apparently does not work on people of color, according to tech blog Phandroid. Many dark-skinned users said the device cannot depict their heart rate sensor — unless if it's put on a lighter area of the body.

"Put a white paper below the sensor and it will work again," a user suggested from the forum, "Mi Band 2 Heart Rate measure not working on Black People."

Users with fairer skin have not seemed to face any mishaps compared to those who are darker. "Heart Rate measure is not working on Black skin, but when it kept in the palm, it is working fine. Please

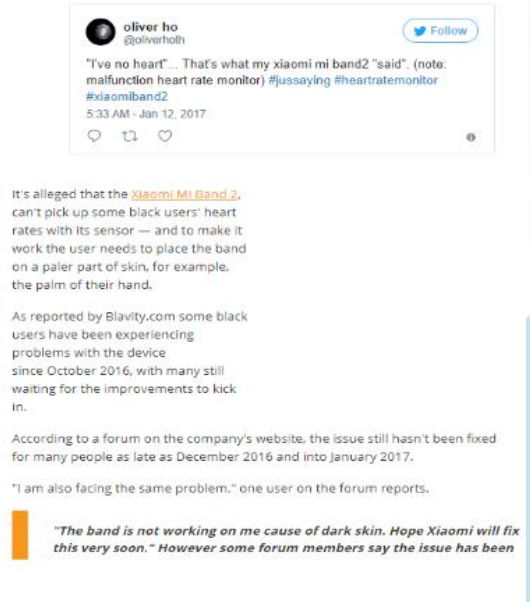
SPUTNIK

Wearable Heart Rate Tracker Missing the Beat When Worn by Black Users

TECH 18:24 17.01.2017 (updated 18:25 17.01.2017) Get short URL

The new year is well underway, with many resolutions of 2017 already being broken, whether it's the fitness regime out of the window, or that the wearable tech not working out for you anymore.

Some black users have complained on forums that the band worn around their wrist cannot decipher their heart rate.



oliver ho
@oliverholh

Follow

"I've no heart"... That's what my xiaomi mi band2 "said". (note: malfunction heart rate monitor) #jussaying #heartratemonitor #xiaomiband2

5:33 AM - Jan 12, 2017

It's alleged that the Xiaomi Mi Band 2, can't pick up some black users' heart rates with its sensor — and to make it work the user needs to place the band on a paler part of skin, for example, the palm of their hand.

As reported by Blavity.com some black users have been experiencing problems with the device since October 2016, with many still waiting for the improvements to kick in.

According to a forum on the company's website, the issue still hasn't been fixed for many people as late as December 2016 and into January 2017.

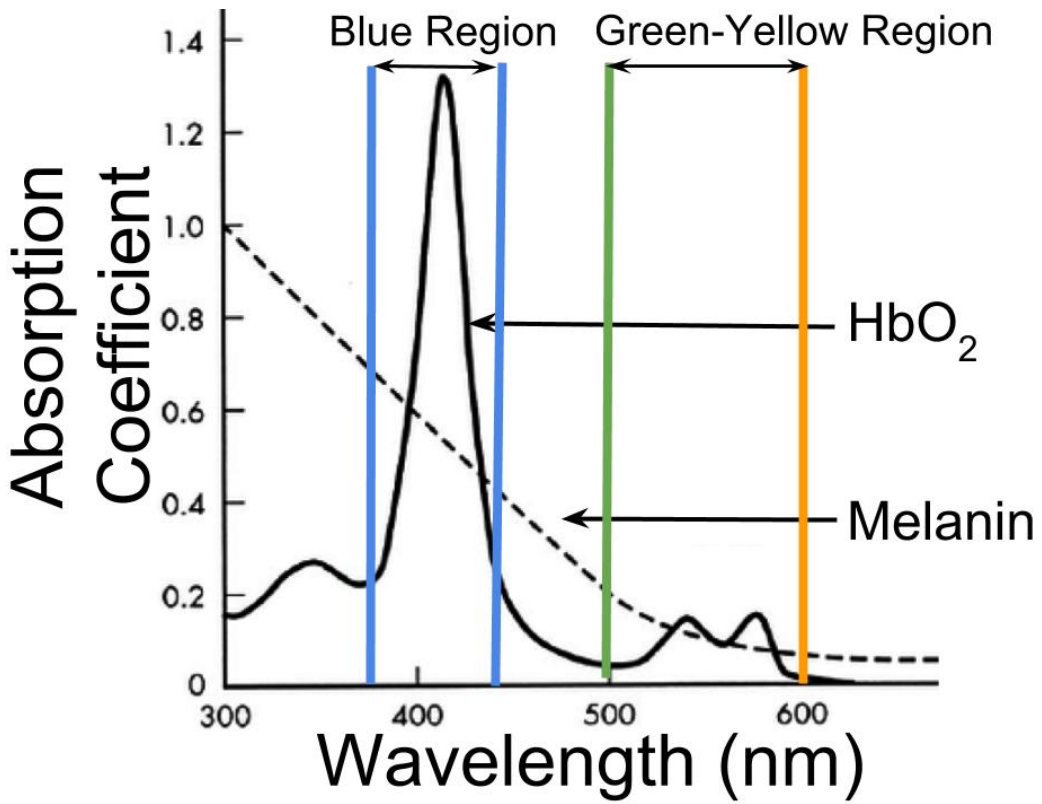
"I am also facing the same problem," one user on the forum reports.

"The band is not working on me cause of dark skin. Hope Xiaomi will fix this very soon." However some forum members say the issue has been

Motivation for a new scheme :

Optical skin property, melanin is a prevalent dermal component in majority of the world's demographics. Sensor must accommodate for this.

Understanding skin-light interaction



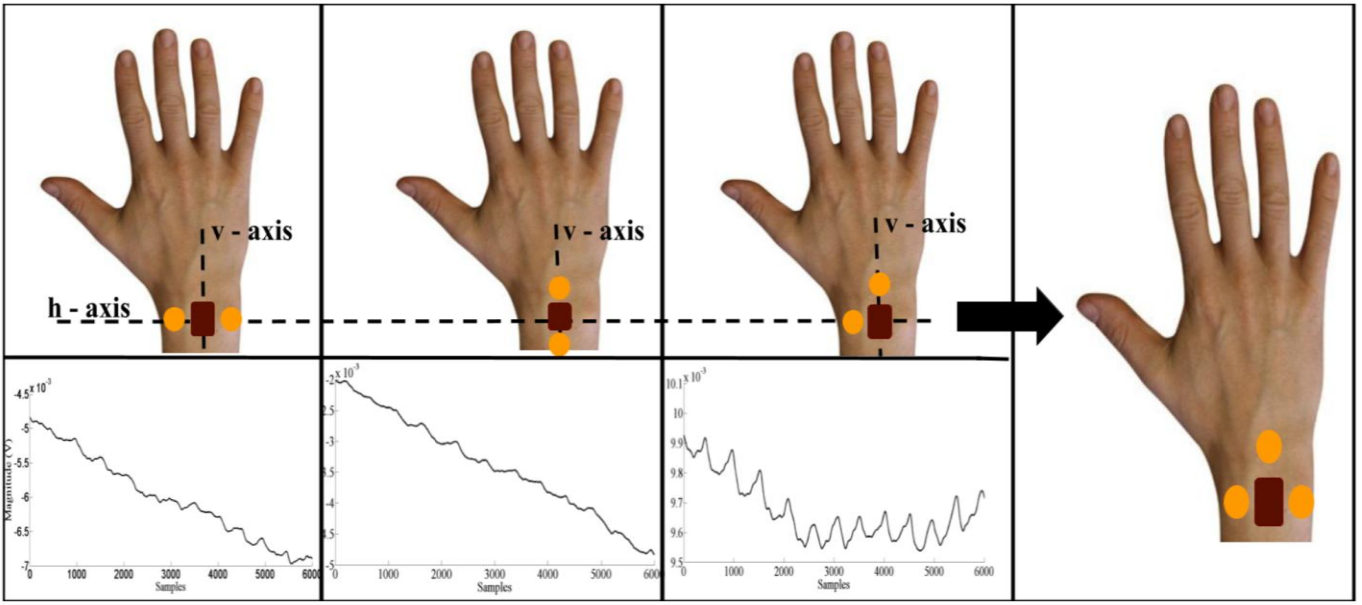
- Melanin absorption- 350nm to 1200nm
- Progressive decrease
- Reflective PPG is superior with visible spectra→ long wavelengths like IR
- Usual choice – 500nm to 540 nm
- Proposed choice – 590nm

Choice of optical elements

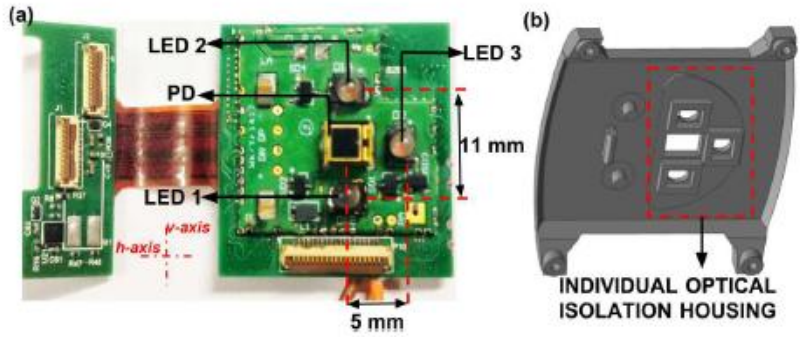
- Optical Emitter (LYT64F)
  - 590 nm
  - Black Packaging
  - Dome lens (30˚)
- Optical Receiver (TEMD5080X01)
  - Wide band (entire visible region)
  - 70 mm^2

Sensor design

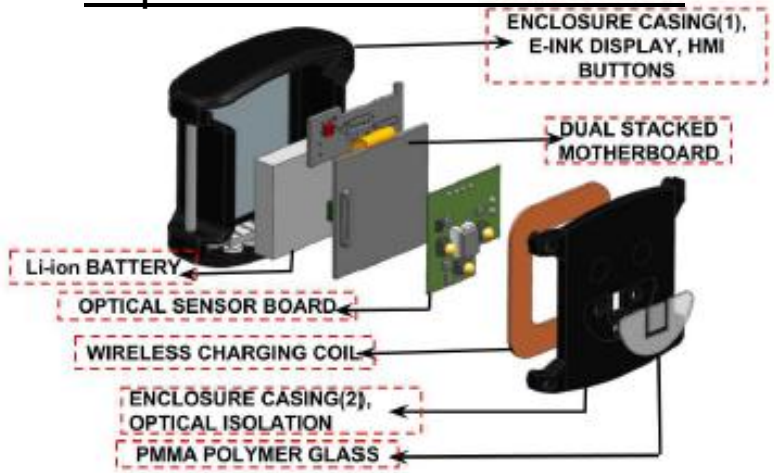
Sensor topology and configuration



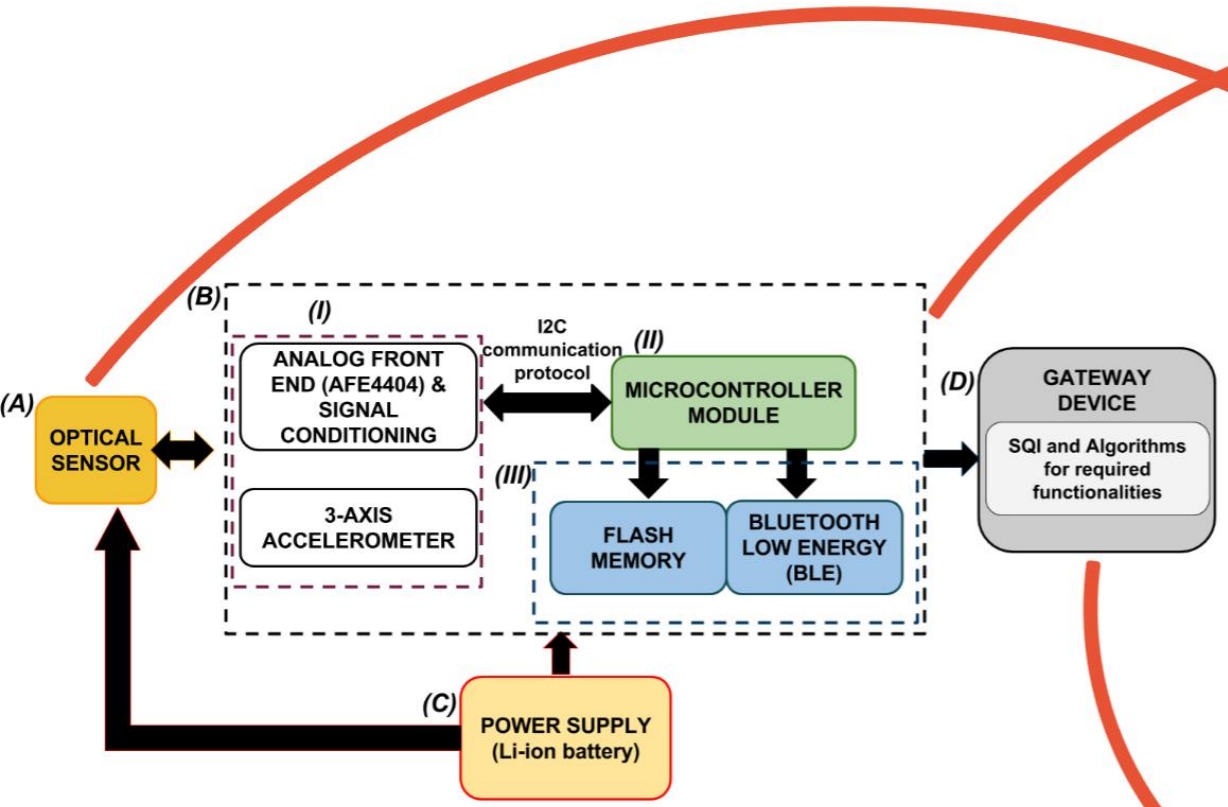
Sensor form-factor and housing

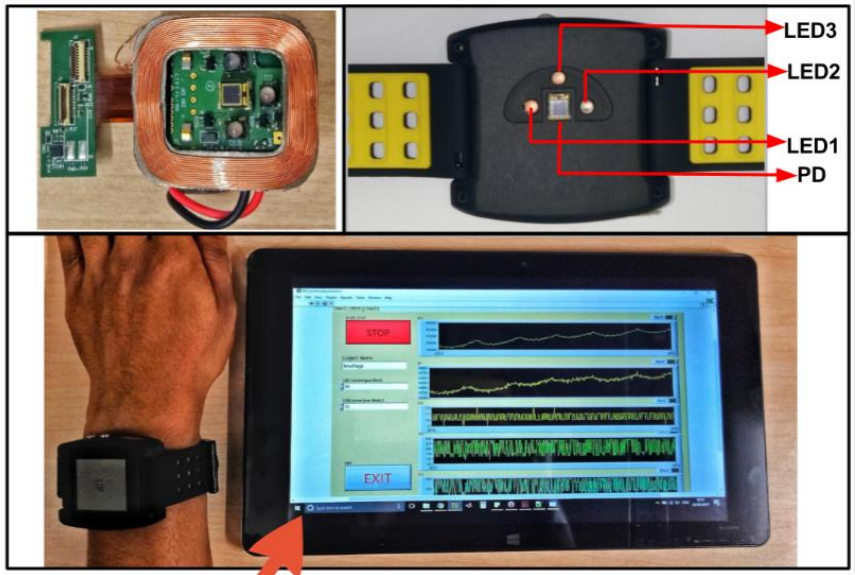


Exploded view of the sensor

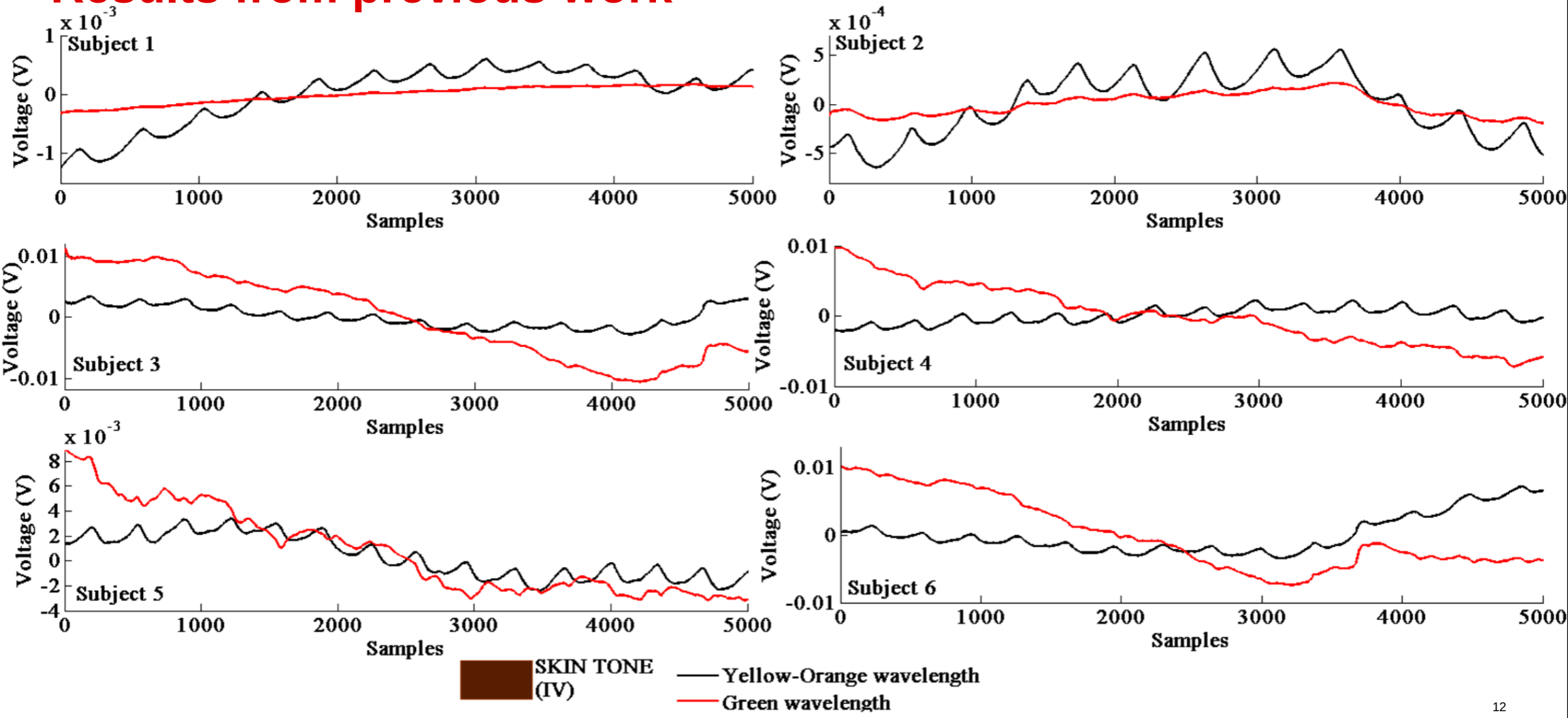


System Architecture





Results from previous work[4]



[4] P. Mohapatra, S. Preejith, and M. Sivaprakasam, “A novel sensor for wrist based optical heart rate monitor,” in *2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) (I2MTC 2017)*, Torino, Italy, May 2017.

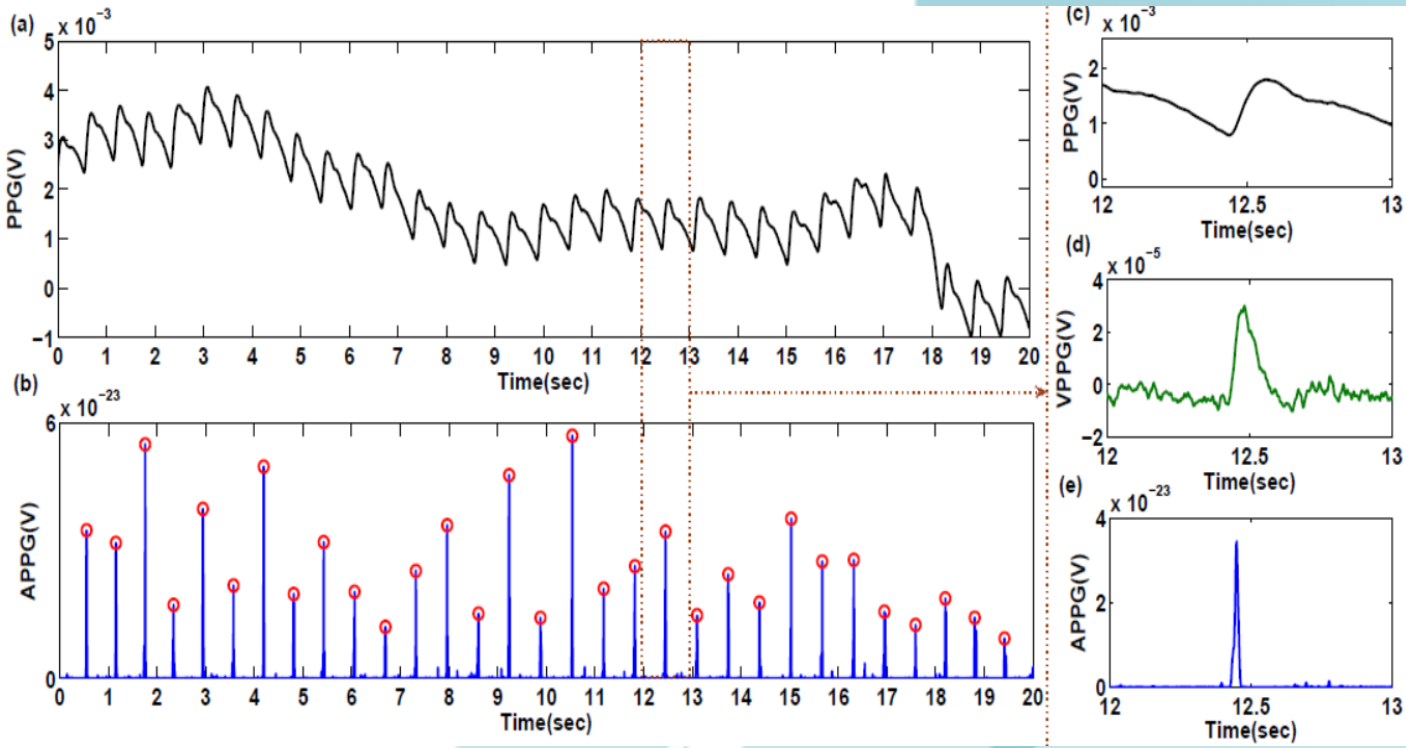
Study objective and Data collection

- **Study Objective** : To investigate the use of in-house developed wrist-wearable to analyse time-domain features of short-term HRV.
- **Subject inclusion** : 5 healthy subjects with an age distribution of 31±3 years.
- **Ambient settings** :
  - Locations : Leh and Pangong Lake of Ladakh.
  - Average temperature : 6◦C, oxygen levels
  - Oxygen level : 82%-92%
  - Altitude : 3400 meters
- **Data Collection**
  - Subjects acclimatized prior to data acquisition.
  - Explained the collection protocol and familiarized with equipment.
  - ECG : eMotion Faros 360◦ (Mega Electronics) in single lead configuration at 1000 Hz.
  - PPG : developed wearable at 500 Hz.

PPG and ECG signals were collected simultaneously.

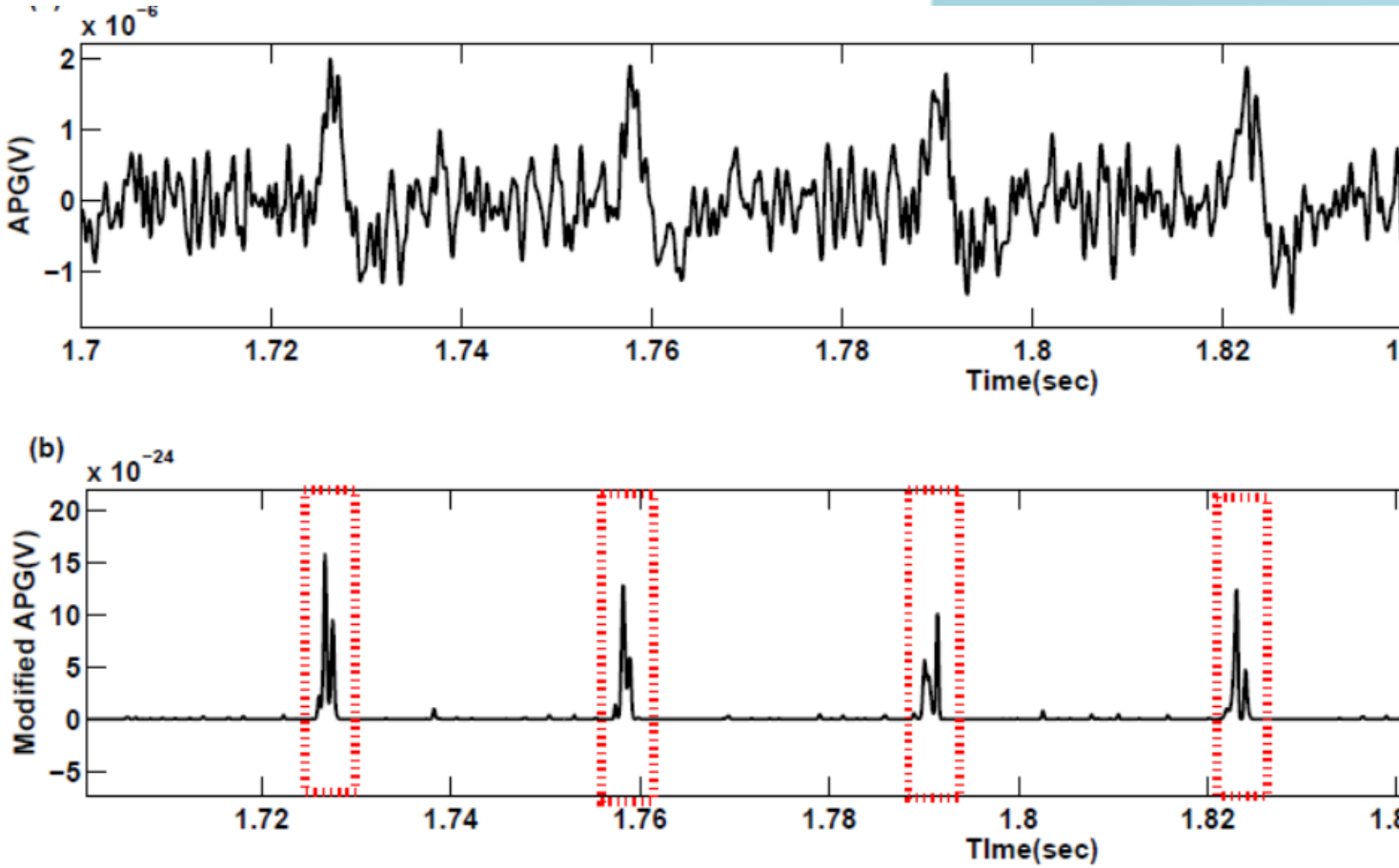
Algorithm used for extracting HRV indices

- Pre-processing : Savitzky-golay filter realized to have a cut-off of 10 Hz.
- Generation of Acceleration Plethysmograph (APG
  - ❑Velocity plethysmogram (VPG) :5-point central difference method
  - ❑Acceleration plethysmogram (APG) : 7-point central difference method



Algorithm used for extracting HRV indices

- Feature extraction
  - ❑ Below zero-baseline nulled and positive part is quadrupled.
  - ❑ Generate blocks of interest.
  - ❑ Maxima in each block - peak of APG
  - ❑Difference between APG peaks denote the PPG interval.



Time-domain HRV indices

Cardiac intervals are referred as NN-intervals.

NN-intervals from ECG are extracted using Pan-Tompkins algorithm[5].

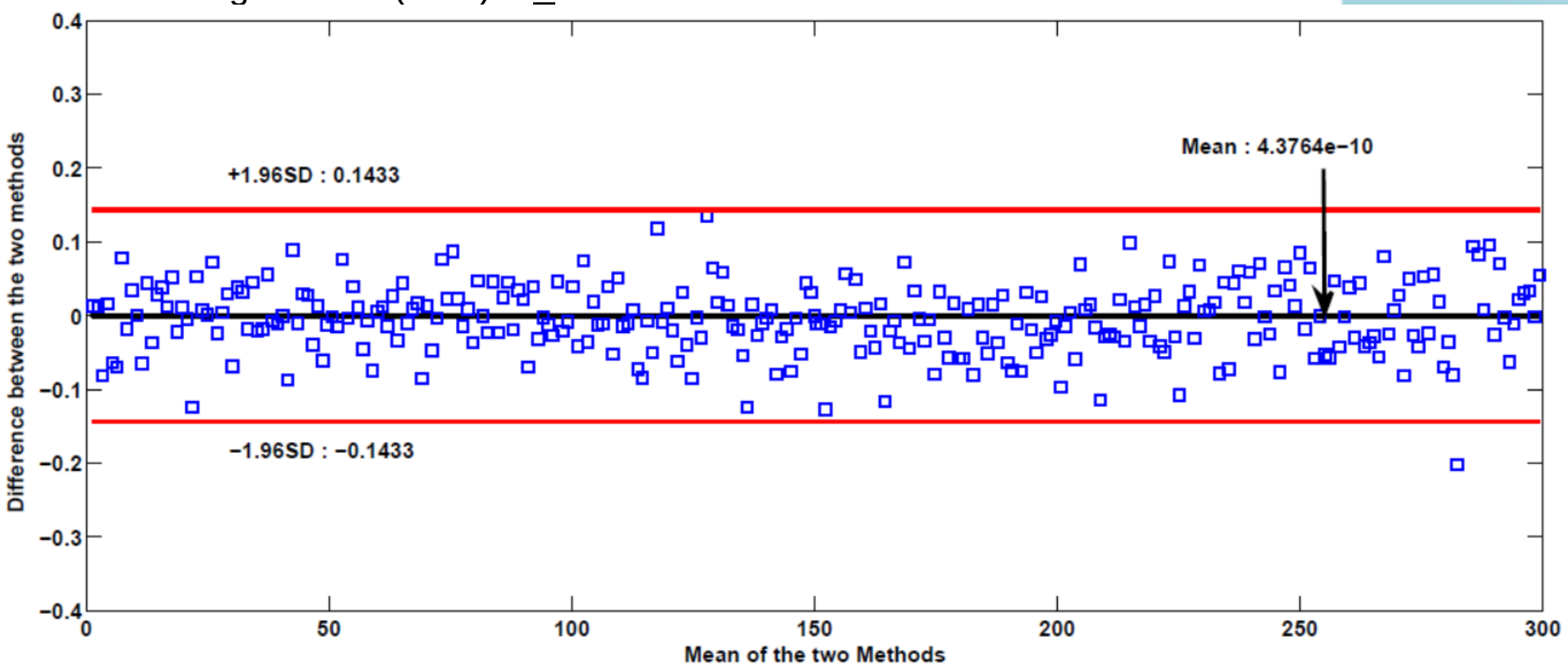
HRV time-domain indices are calculated from both ECG and PPG NN-intervals using the following definitions:

RMSSD	**Root mean square of successive difference**
SDNN	**Standard deviation between NN-intervals**
SDSD	**Standard deviation of successive differences**
pNN50	**Ratio of the number of NN-intervals greater than 50 ms to the total number of NN-intervals**

[5] J. Pan and W. J. Tompkins, “A real-time qrs detection algorithm,” *IEEE transactions on biomedical engineering*, no. 3, pp. 230–236, 1985.

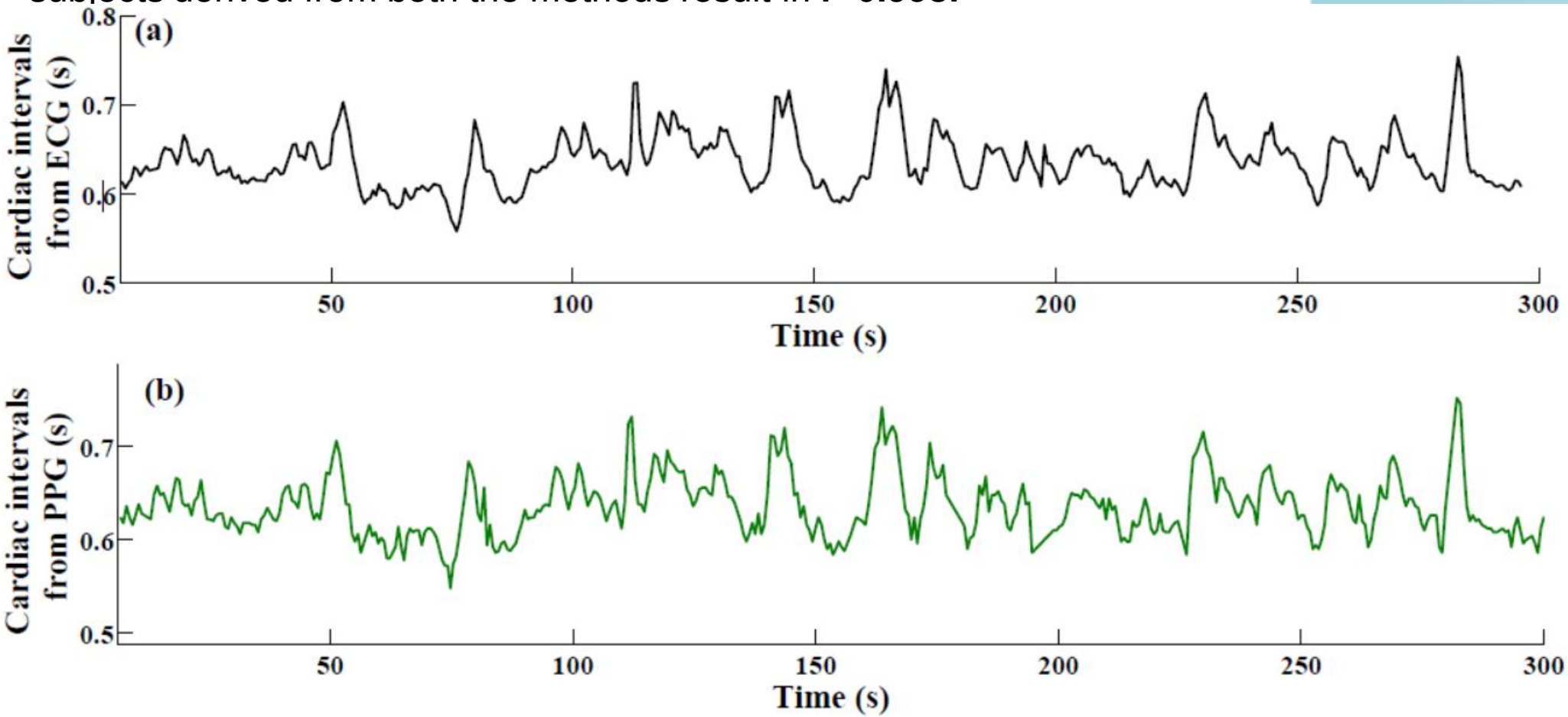
Experimental Results

- Bland-Altman plot to show the agreement between measurements from both methods.
- Limits of agreement (LOA) = ± 95%



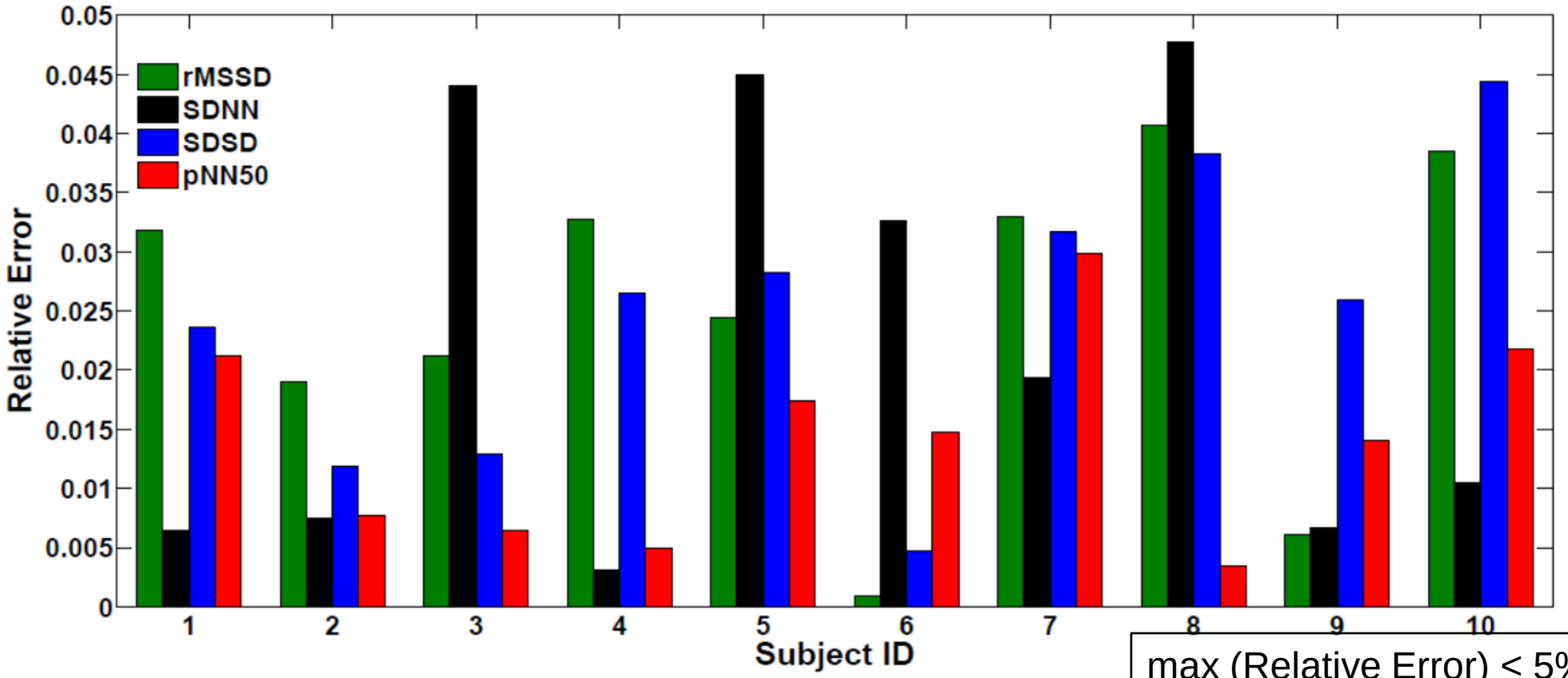
Experimental Results

- Pearson's correlation(r) to verify the temporal similarity between the tachograms for all the subjects derived from both the methods result in **r>0.995.**



Experimental Results

$$RelativeError = \frac{|ECG_{metric} - PPG_{metric}|}{ECG_{metric}}$$



max (Relative Error) < 5%

Conclusions

- Designed optical sensor provides high-quality signals even at extremely low perfusion levels.
- Our results indicate that the differences between the HRV derived parameters obtained from PPG are statistically insignificant (within 95% of agreement) from the gold-standard.
- Developed wearable can be used for short term HRV monitoring. Another study[6] to conducted on various orthostatic loads over 60 data-sets support this result. (Published in TIM, 2018)
- This opens up the prospect of HRV monitoring not just restricted to ambulatory events and extensively expands the serviceability of HRV.

Future Work

- Algorithm is implemented in MATLAB 2016 which can be implemented as an application on the host processor.

This would make it a comprehensive measurement system.

- Similarly data acquisition system can be further optimized and curated to allow better user experience.

P. Mohapatra, P. S. Premkumar, and M. Sivaprakasam, “A yellow–orange wavelength-based short-term heart rate variability measurement scheme for wrist-based wearables,” *IEEE Transactions on Instrumentation and Measurement*, vol. 67, no. 5, pp. 1091–1101, 2018.

THANK YOU!