Design of wearable and non-wearable cardiac monitoring system

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My research field

2007 2009 2011 2013 2015 2017

Efficient protocol for wireless communication

Low-power and accurate bio-signal monitoring system (includeing algorithm, circuit, and architecture design)

Low-power circuit design for sensor network

Non-wearable sensors

Flooding protocol for wireless sensor networks

Ultra-low-power sensor node SoC for wireless sensor networks

Wireless microphone-array network system

Low-power PLL for sensor network

Physical activity monitoring LSI for wearable sensors

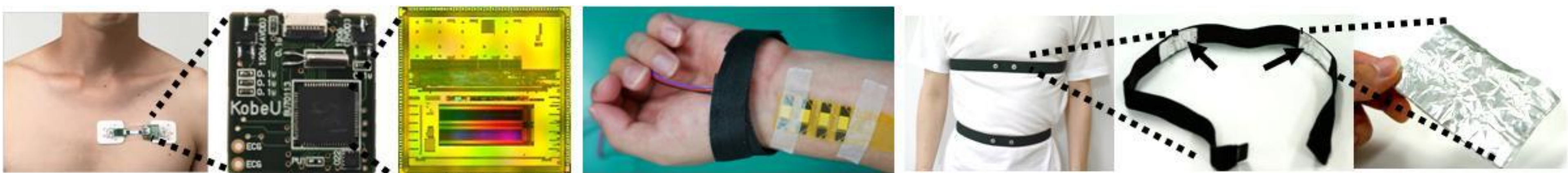
Noise tolerant heart rate extraction algorithm for wearable sensors

Non-volatile memory and microcontroller for wearable sensors

Ingestible, long-term GI monitoring system

Ultra-low-power PPG

Non-contact cardiac monitoring systems



Objective of this research

- **Application:** Heart rate (variability) monitoring for Stress, Sleep, and Cardiac disease monitoring

- **Method:** Wearable and non-wearable cardiac sensing

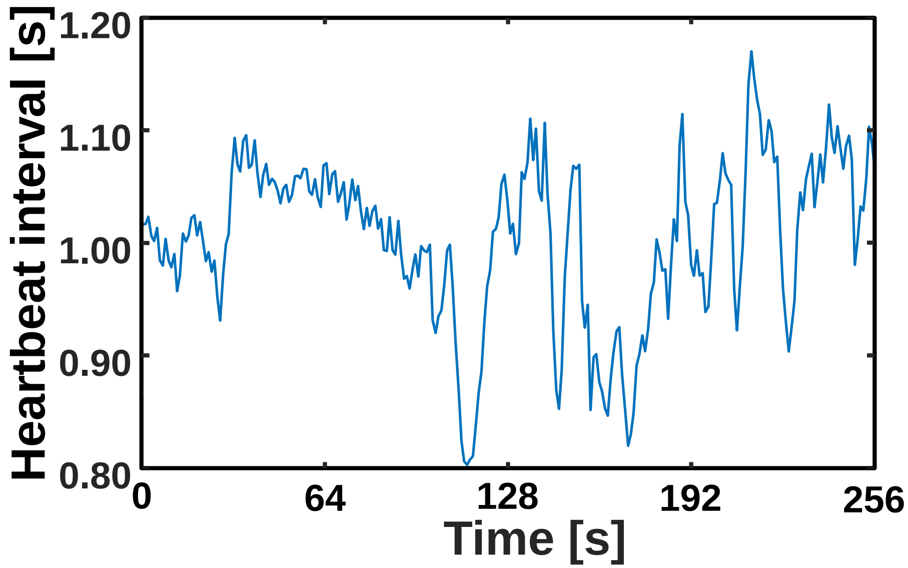
- **Issue:**

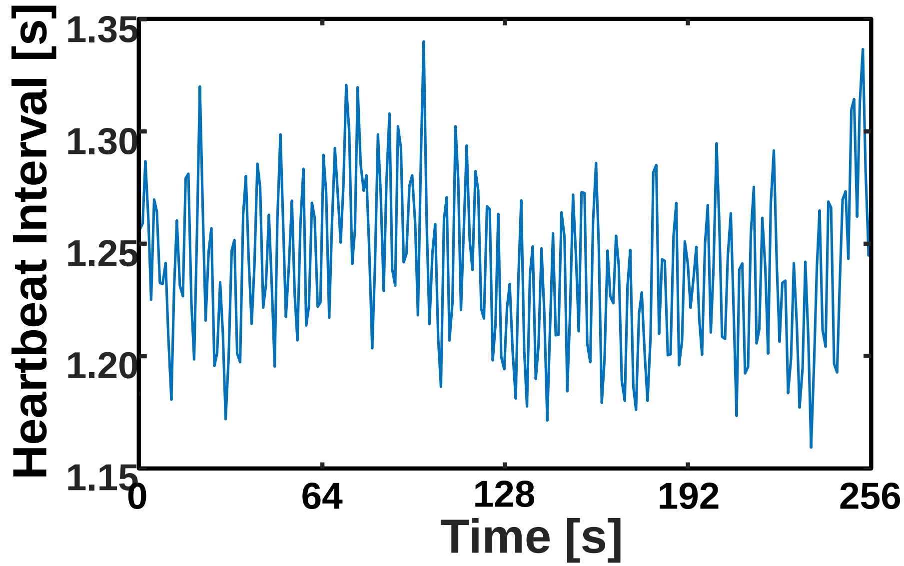
  Power reduction for long battery life

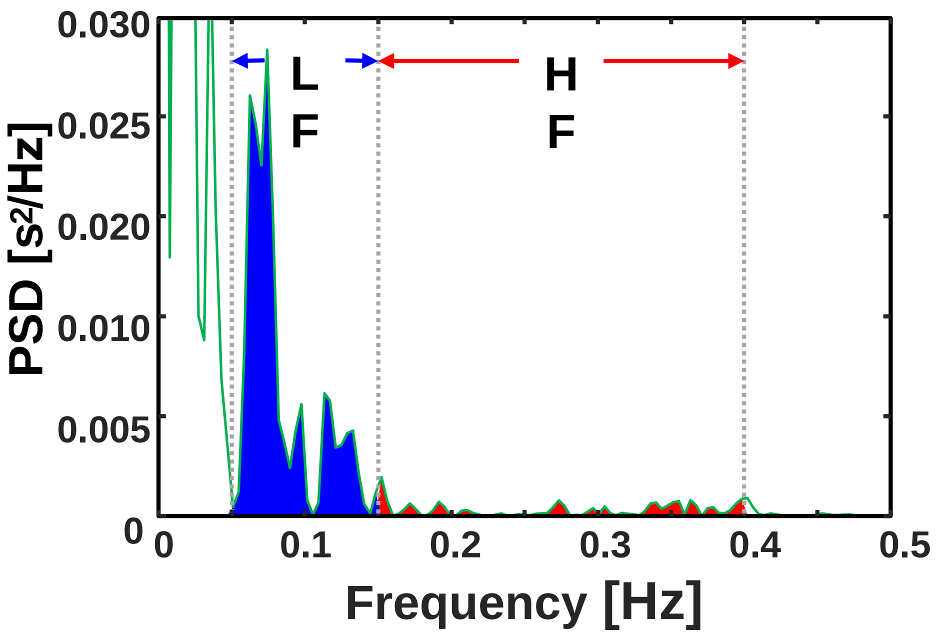
  Non-contact monitoring

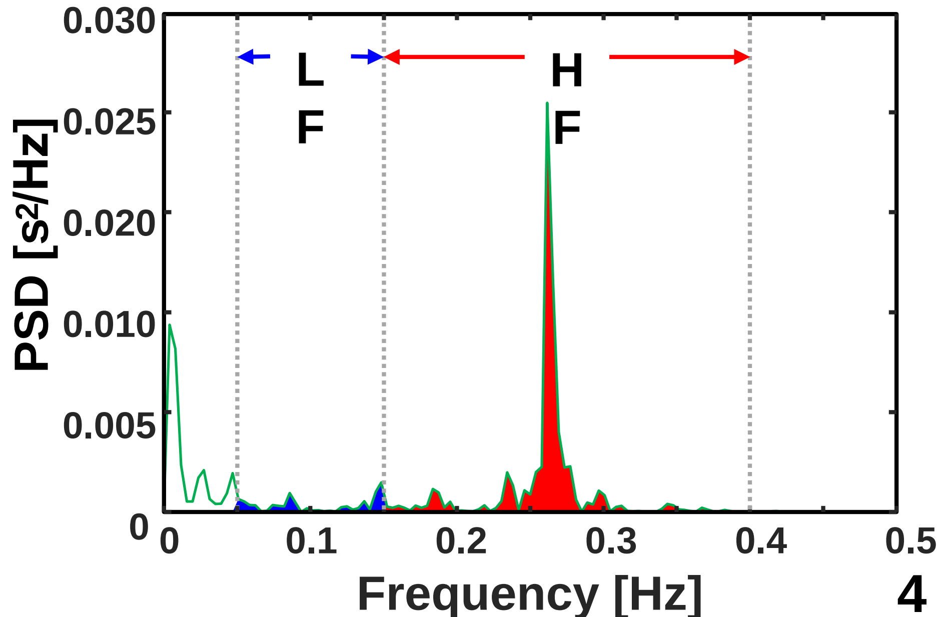
  Noise reduction and accurate sensing

Example of Heart Rate Variability









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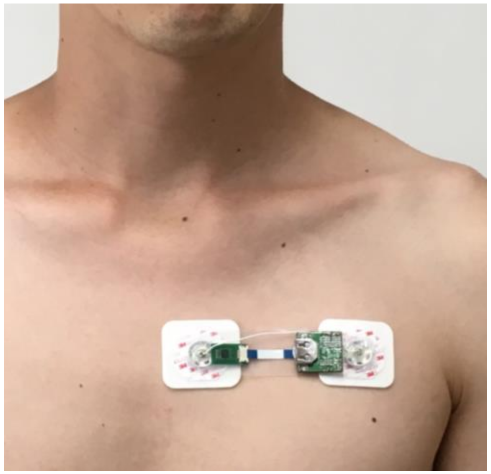
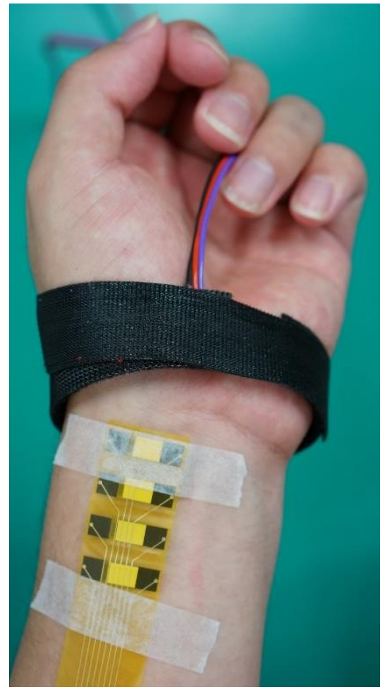
Roadmap

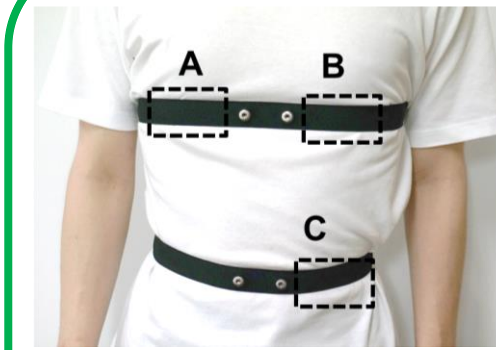


Ultra-low-power ECG and PA sensor.

Paste-type (body trunk)



Paste-type (wrist)



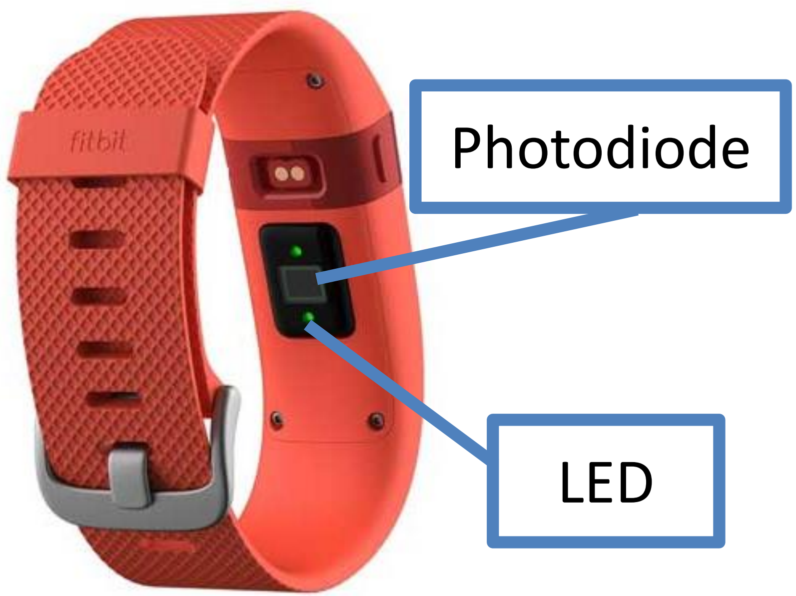
Non-contact

1) Ultra-low-power pulse wave (PPG) sensor

2) Capacitively coupled ECG sensor

3) Microwave Doppler (heartbeat) sensor

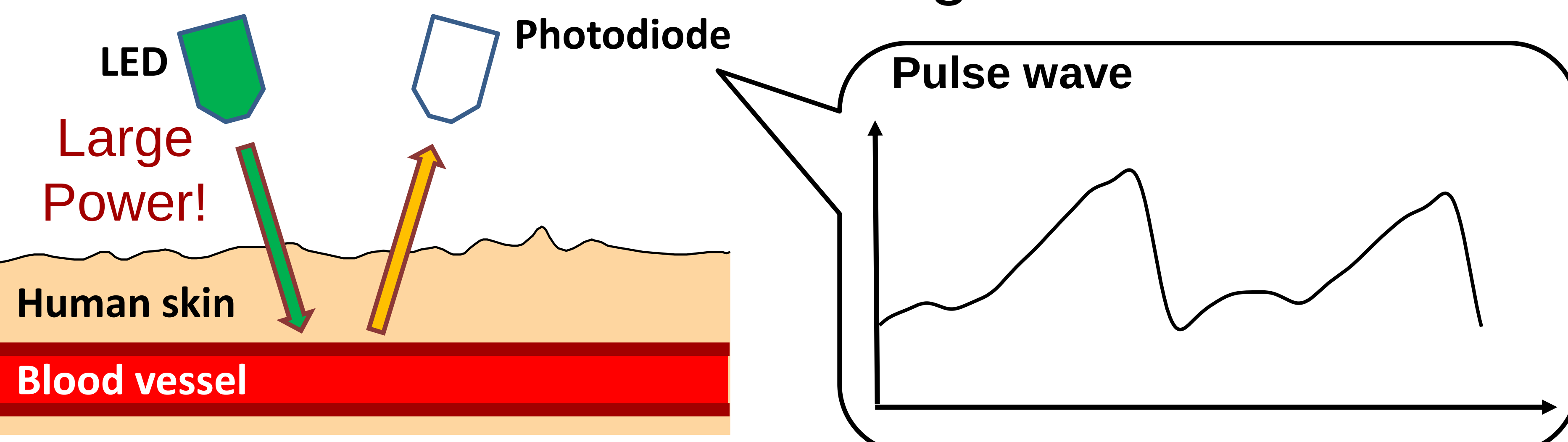
PPG (pulse wave) sensor



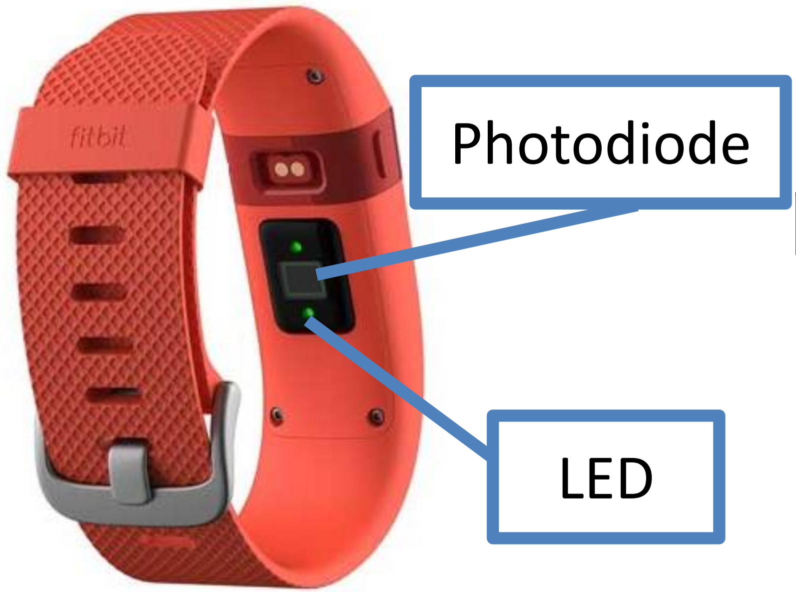
1) Irradiate green light to the body surface

2) Measures the amount of light absorption by hemoglobin

→Related to the volume change of blood vessel

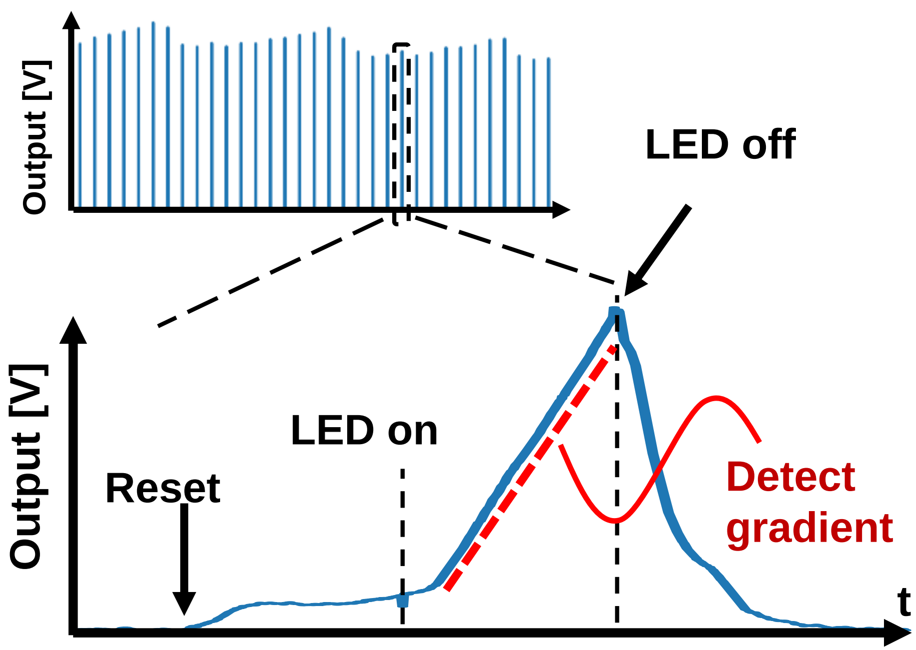


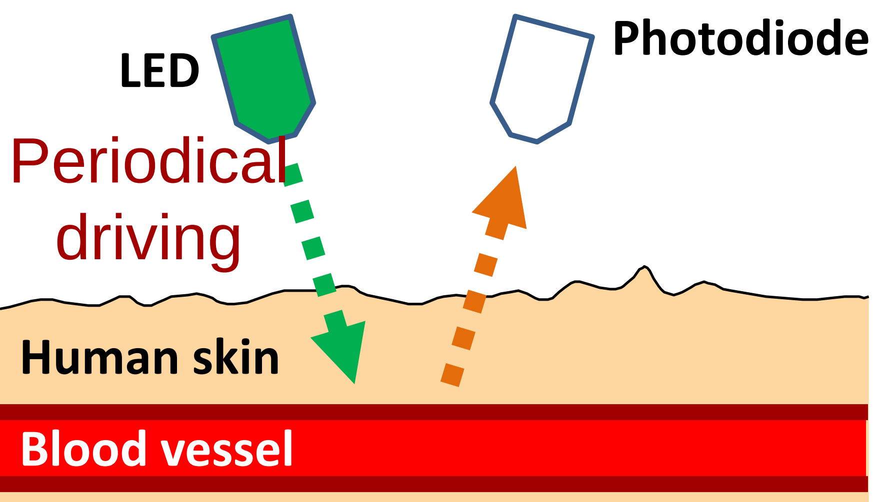
Ultra-low-power PPG sensor



Proposed method:

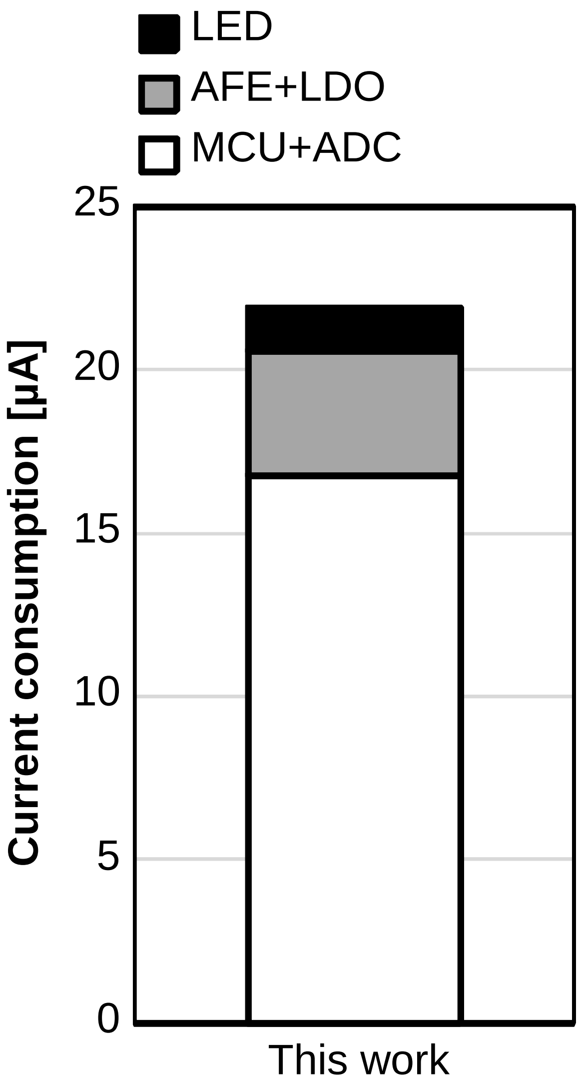
1) New circuit design for periodical LED driving





2) Upconversion algorithm for active rate reduction

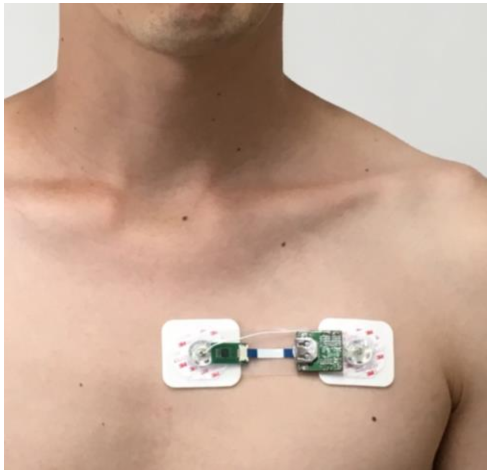
Ultra-low-power PPG sensor



	This work	[1]	[2]
Photo detection circuit	Current integration	TIA	TIA
Sampling Freq.	16 Hz	128,16,13 and 4 Hz	N/A
Feature Extraction	Pulse Interval	Pulse Interval	Pulse Interval
Heart beat interval error	4.77 ms (MAE)	2 bpm	N/A
Supply voltage	3V	1.2V	1.5V and 1.2V (Digital), 3.3V (LED)
Current consumption (w/o LED)	20.6 μA	143 μA	35.78 μA
Current consumption (w/ LED)	21.9 μA	178.8 μA	155.8 μA

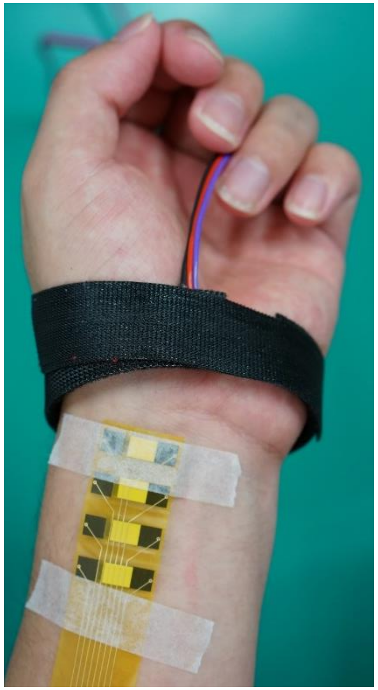
[1] V. R. Pamula et al., IEEE Trans. BioCAS, vol. 11, no. 3, pp. 487–496, June 2017.
[2] A. Sharma et al., IEEE Journal of Solid-State Circuits, vol. 52, no. 4, pp. 1021–1033, April 2017.

Roadmap

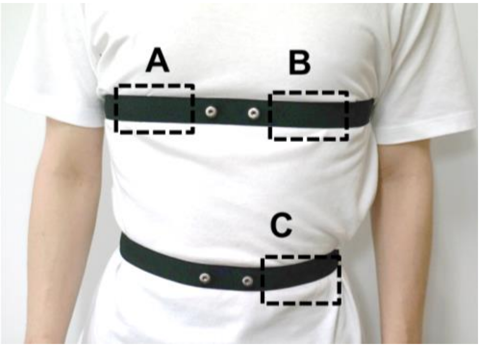


Ultra-low-power ECG
and PA sensor.

Paste-type
(body trunk)



Paste-type
(wrist)



Non-contact

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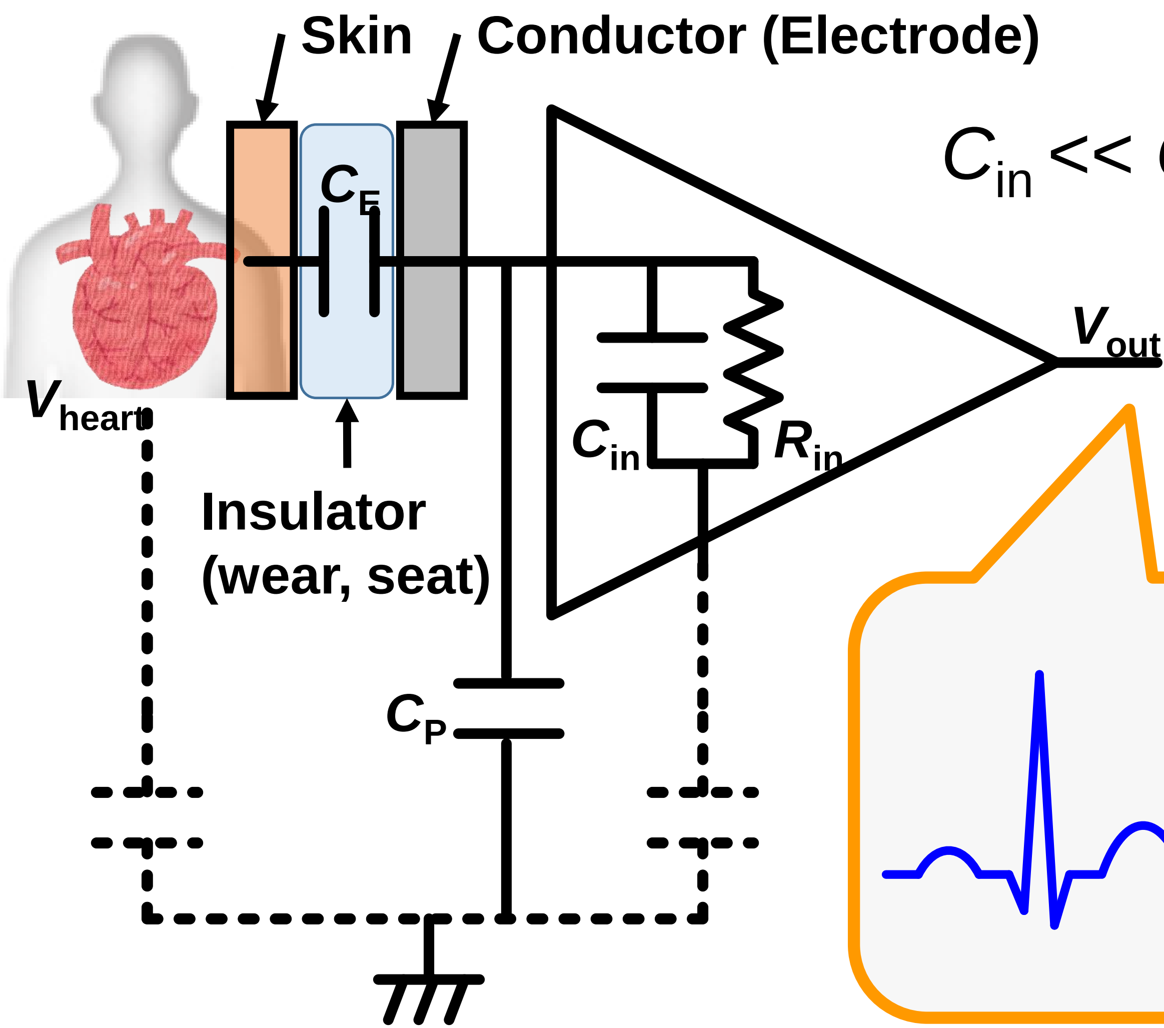
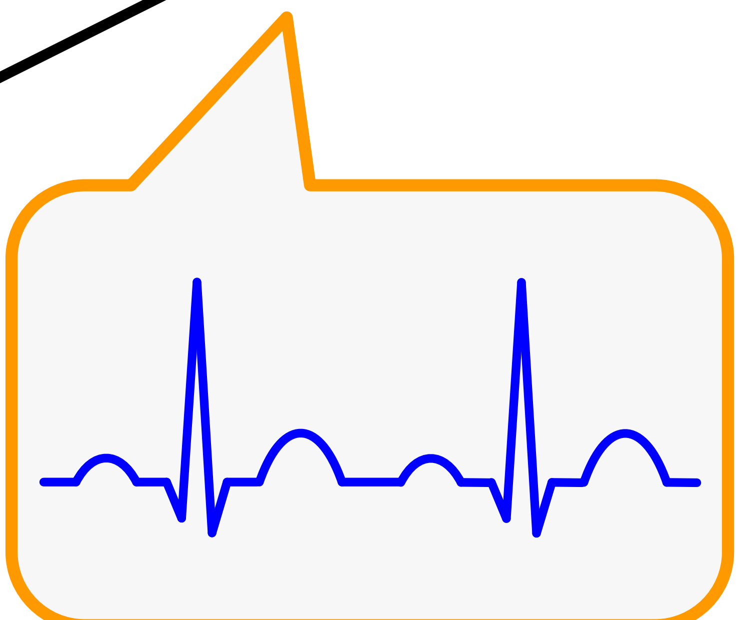
Capacitively coupled ECG

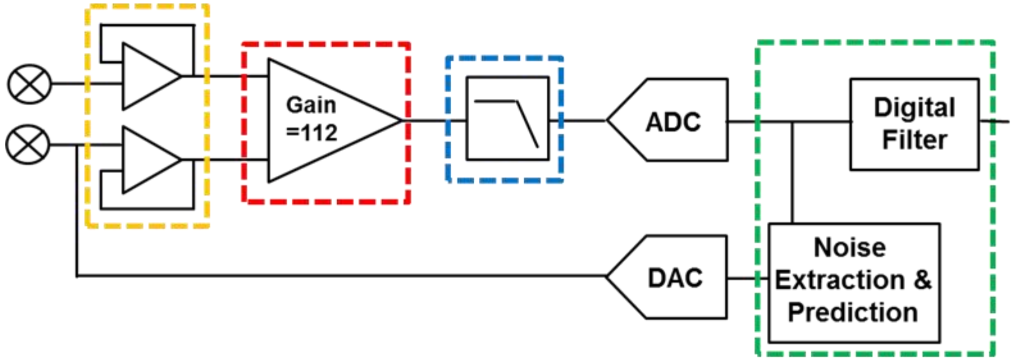


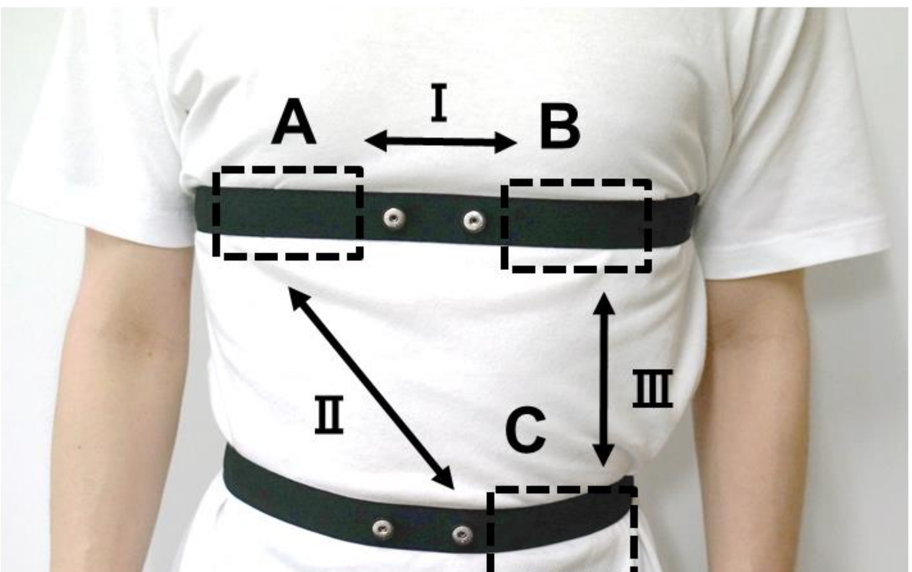
$C_{in} << C_E \rightarrow V_{out} \approx V_{heart}$



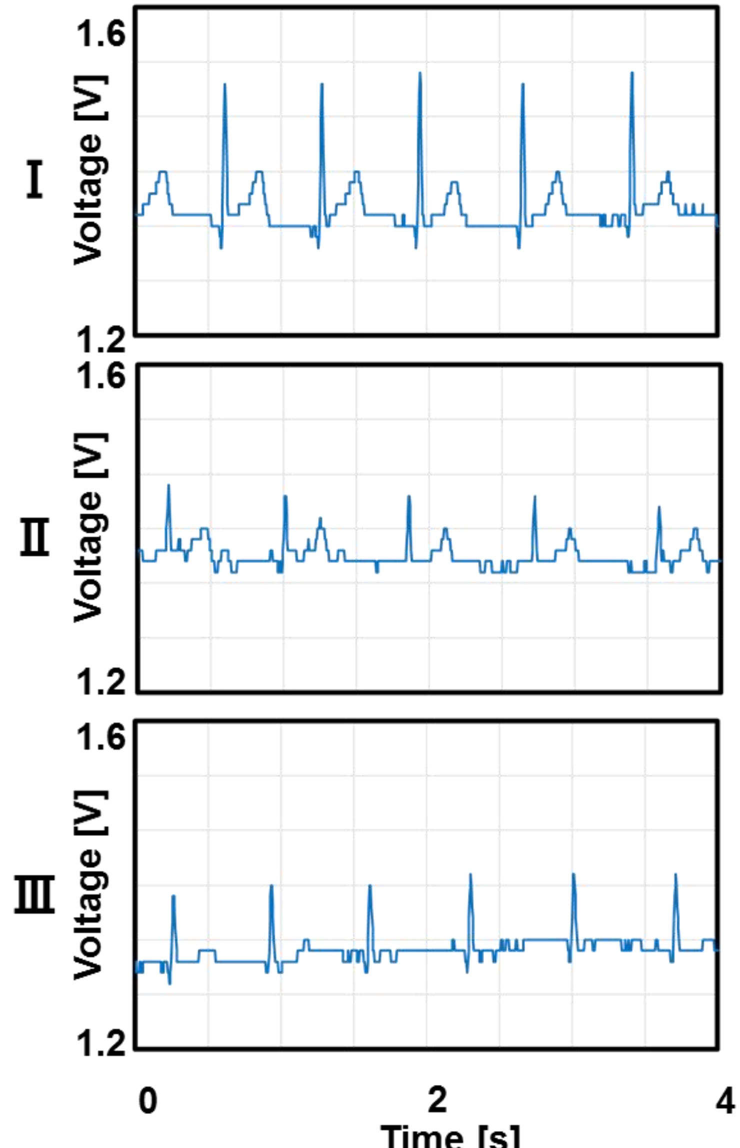
Electrocardiogram(ECG)

Capacitively coupled ECG





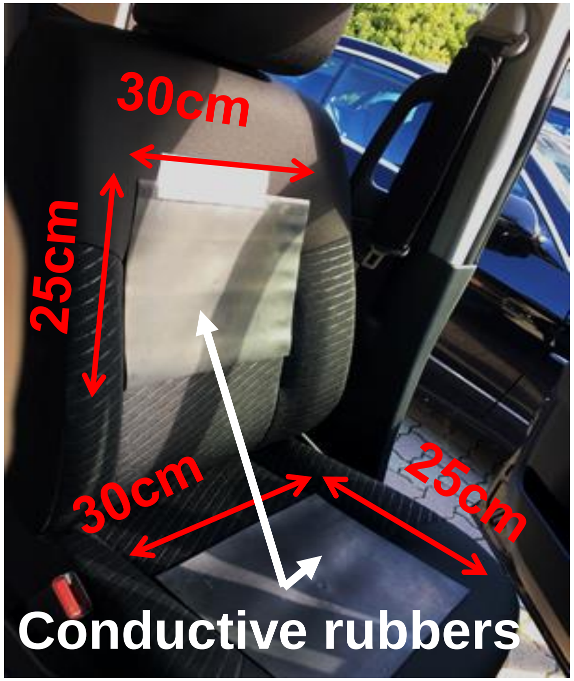
Conductive rubber electrodes

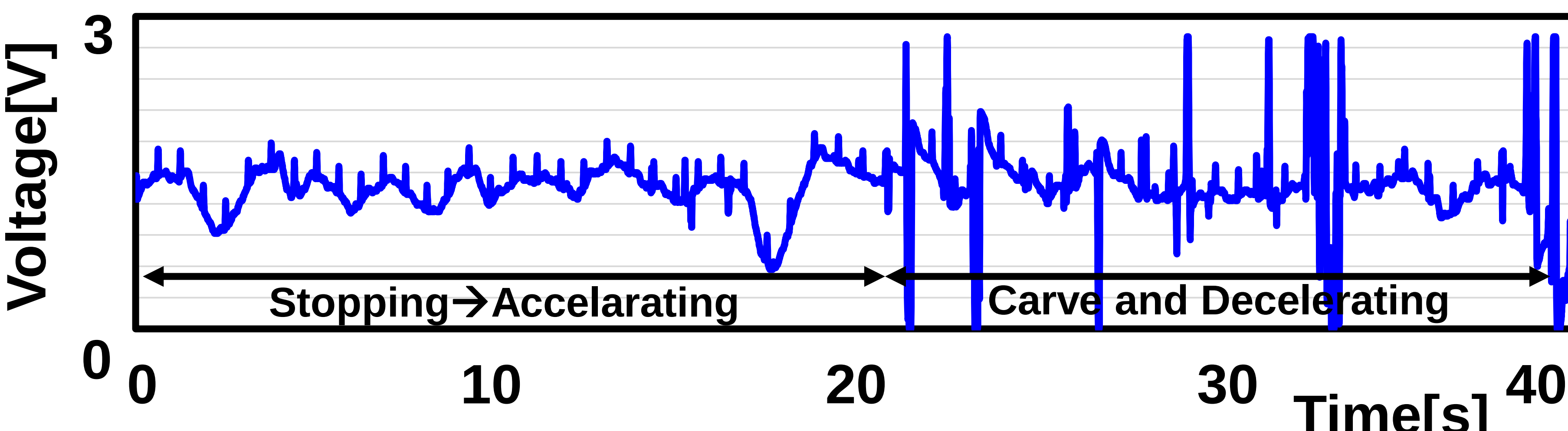


Noise feed-back is effective to availability.

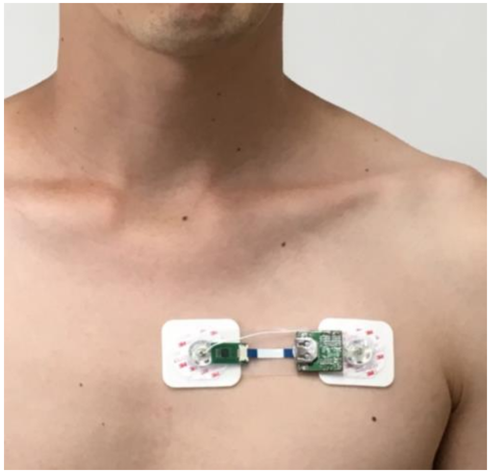
Capacitively coupled ECG

Capacitively coupled ECG



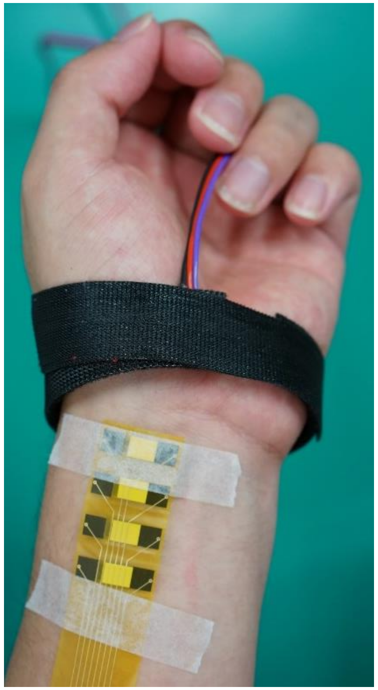


Roadmap



Ultra-low-power ECG and PA sensor.

Paste-type (body trunk)



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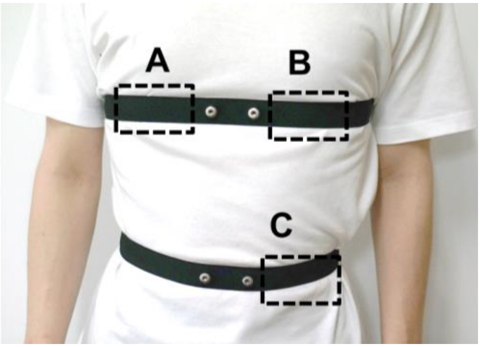

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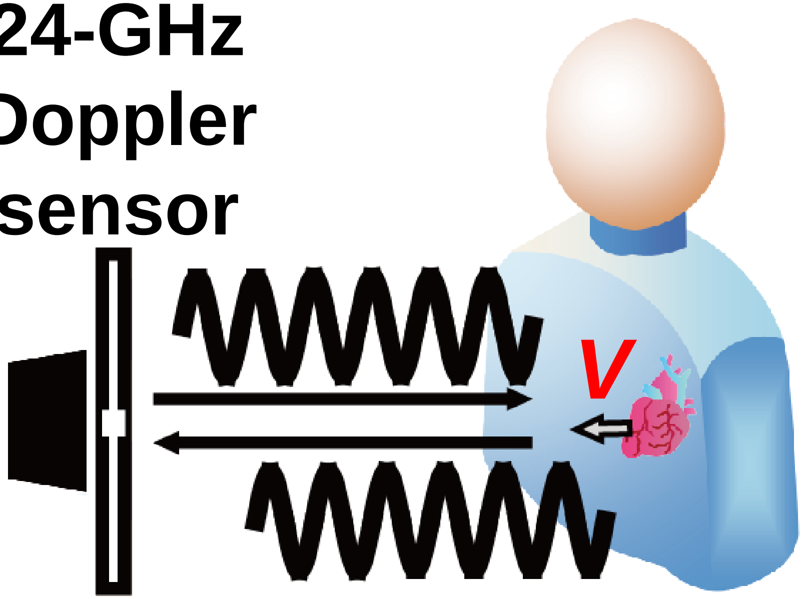
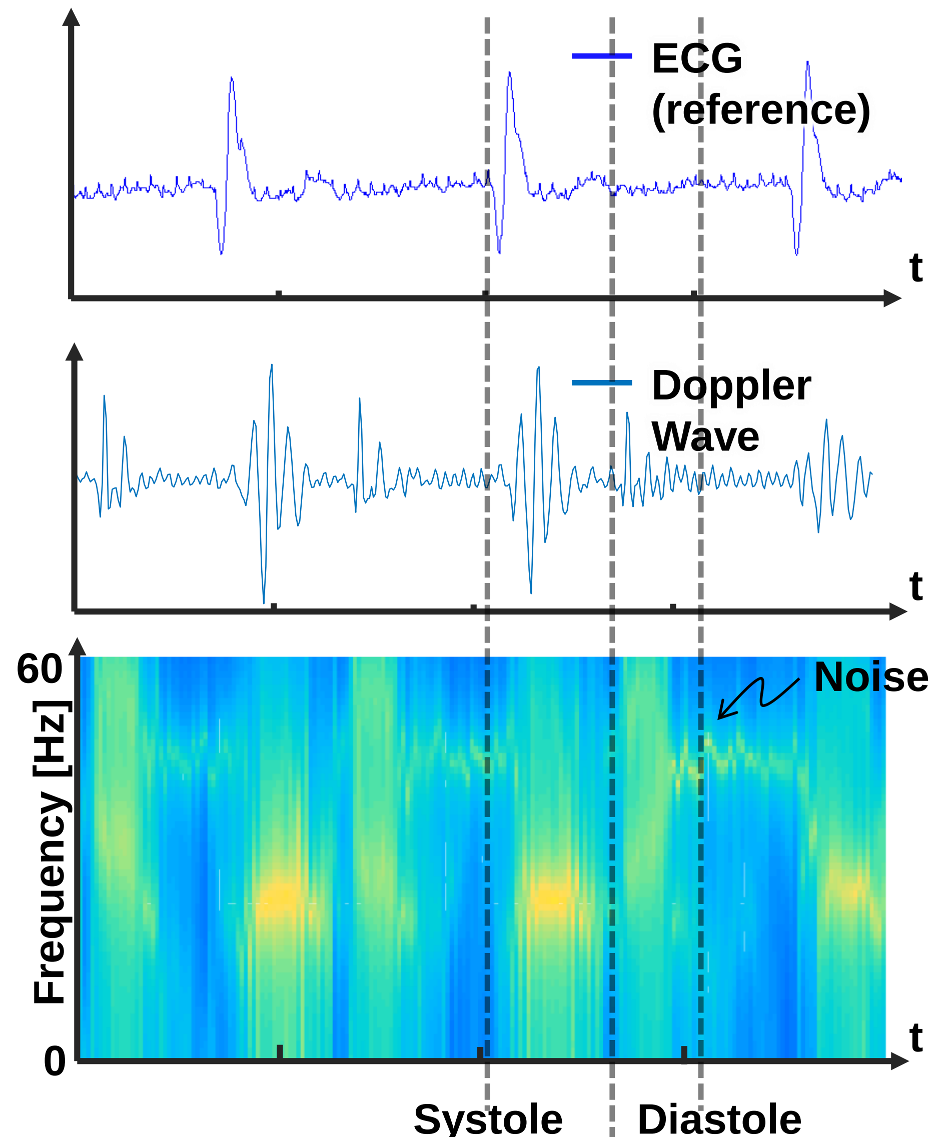
Microwave Doppler sensor

24-GHz Doppler sensor





Output:

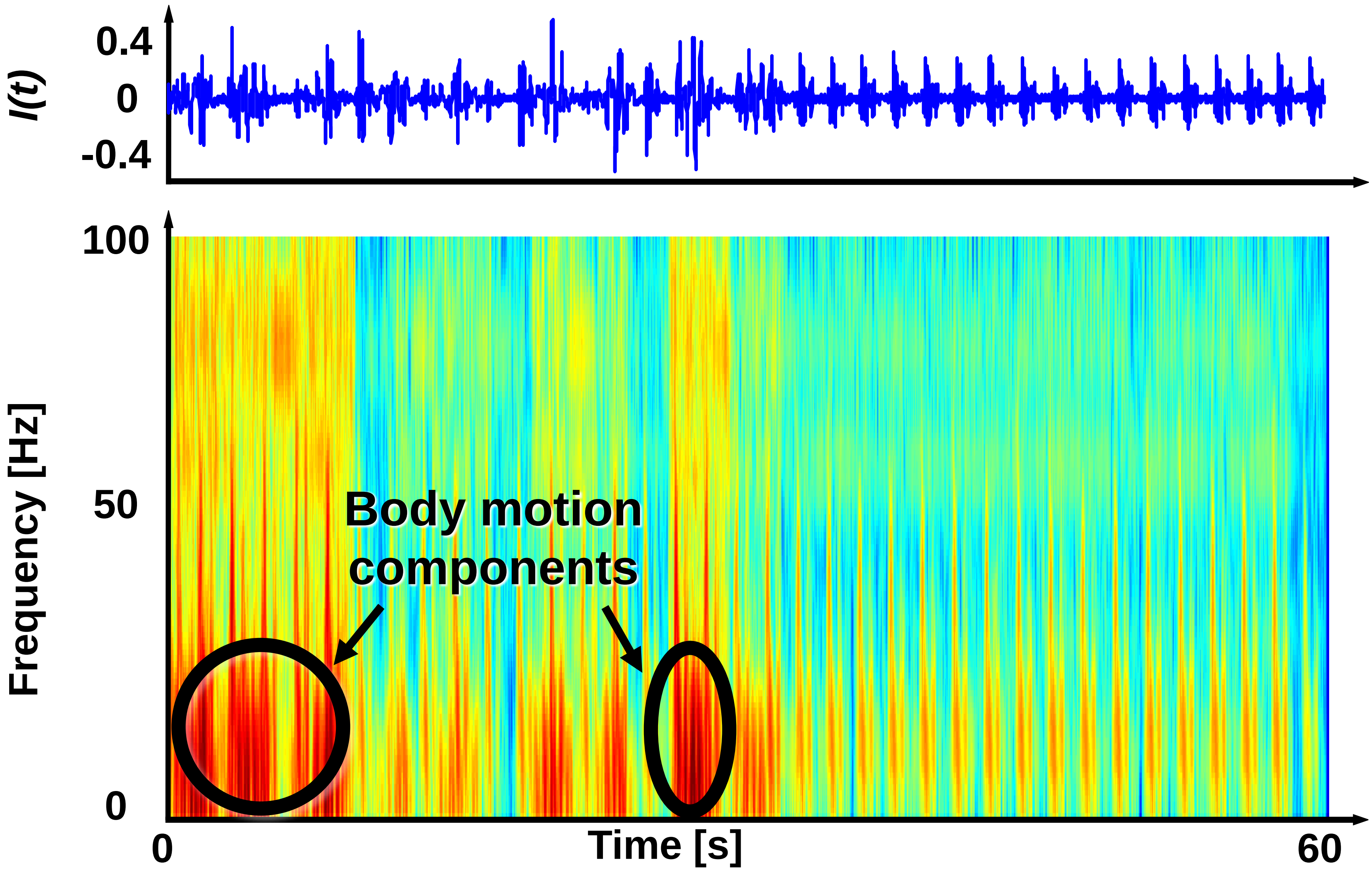
$$I(t) = A\sin\left(\frac{2V}{\lambda}\times 2\pi t\right)$$

λ :wave length

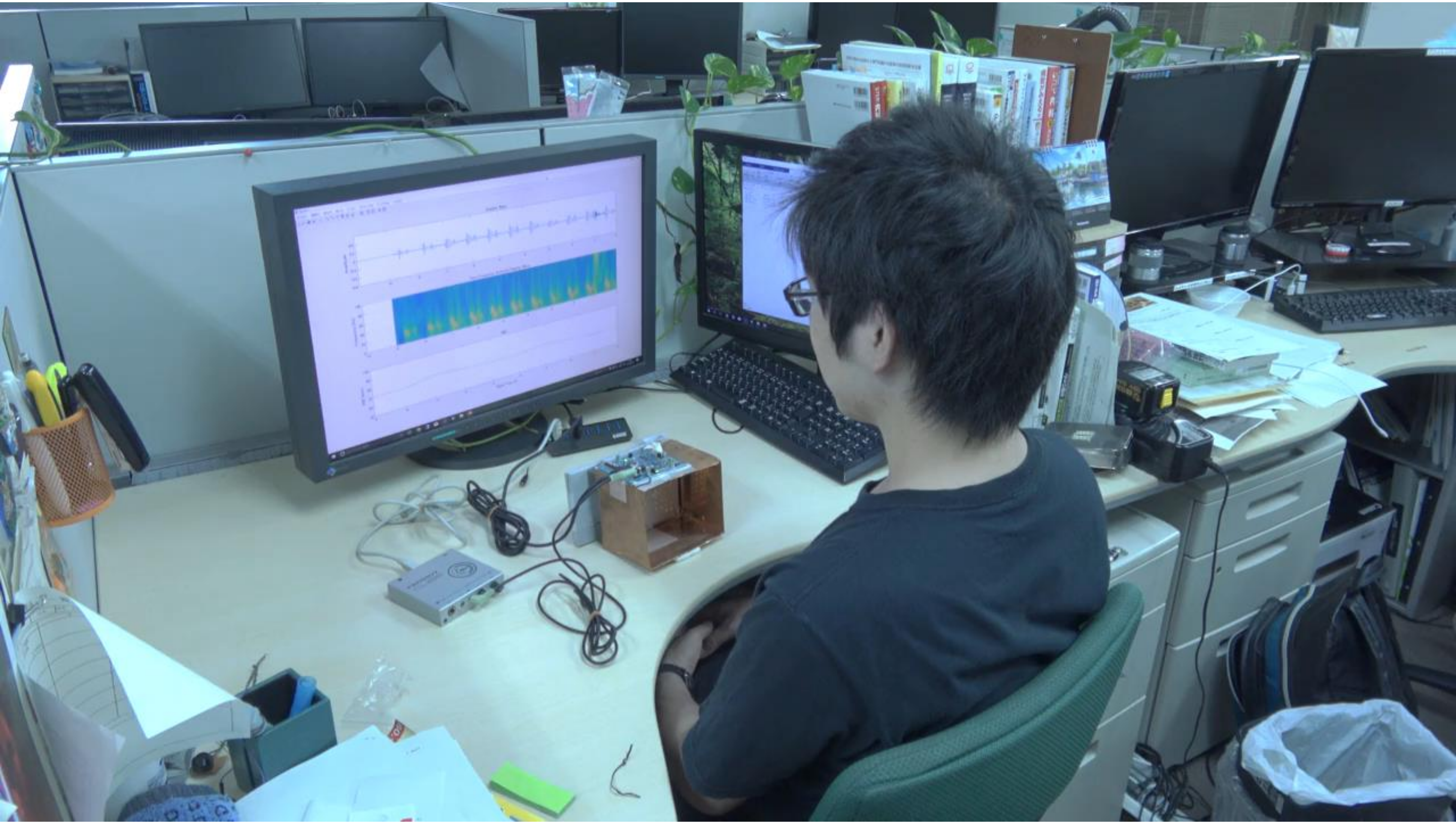
V: velocity of body surface

Contact-less, but sensitive to noises.

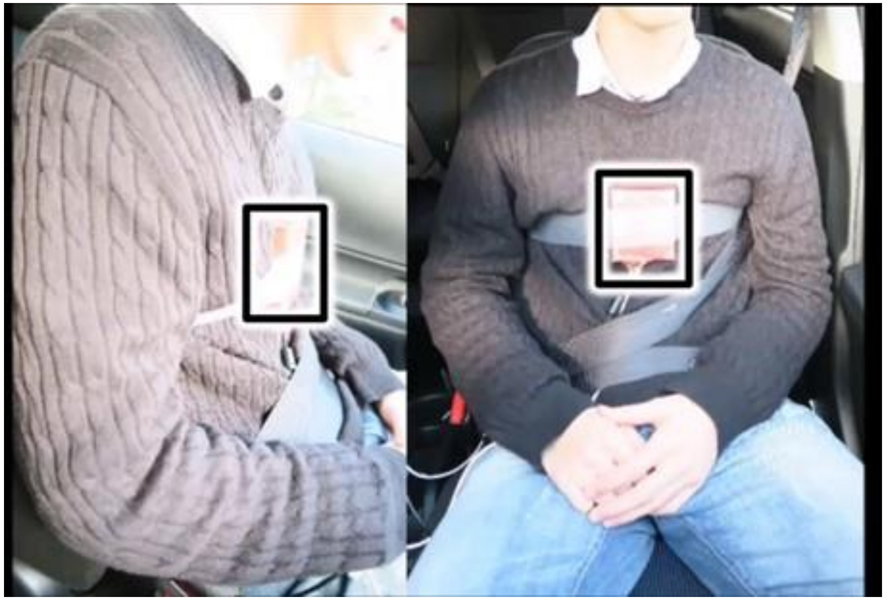
Example of time-frequency analysis

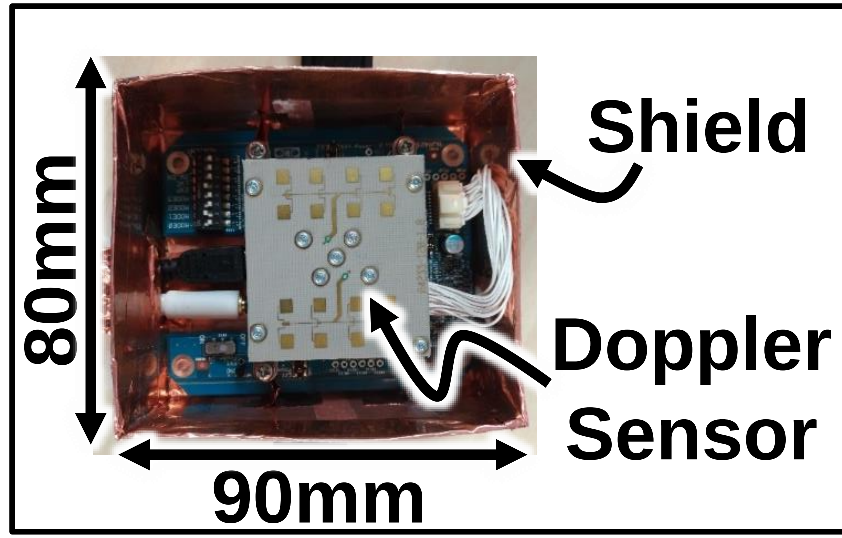


Microwave Doppler sensor



Microwave Doppler sensor





2 females and 9 men

From 22 to 36 years old

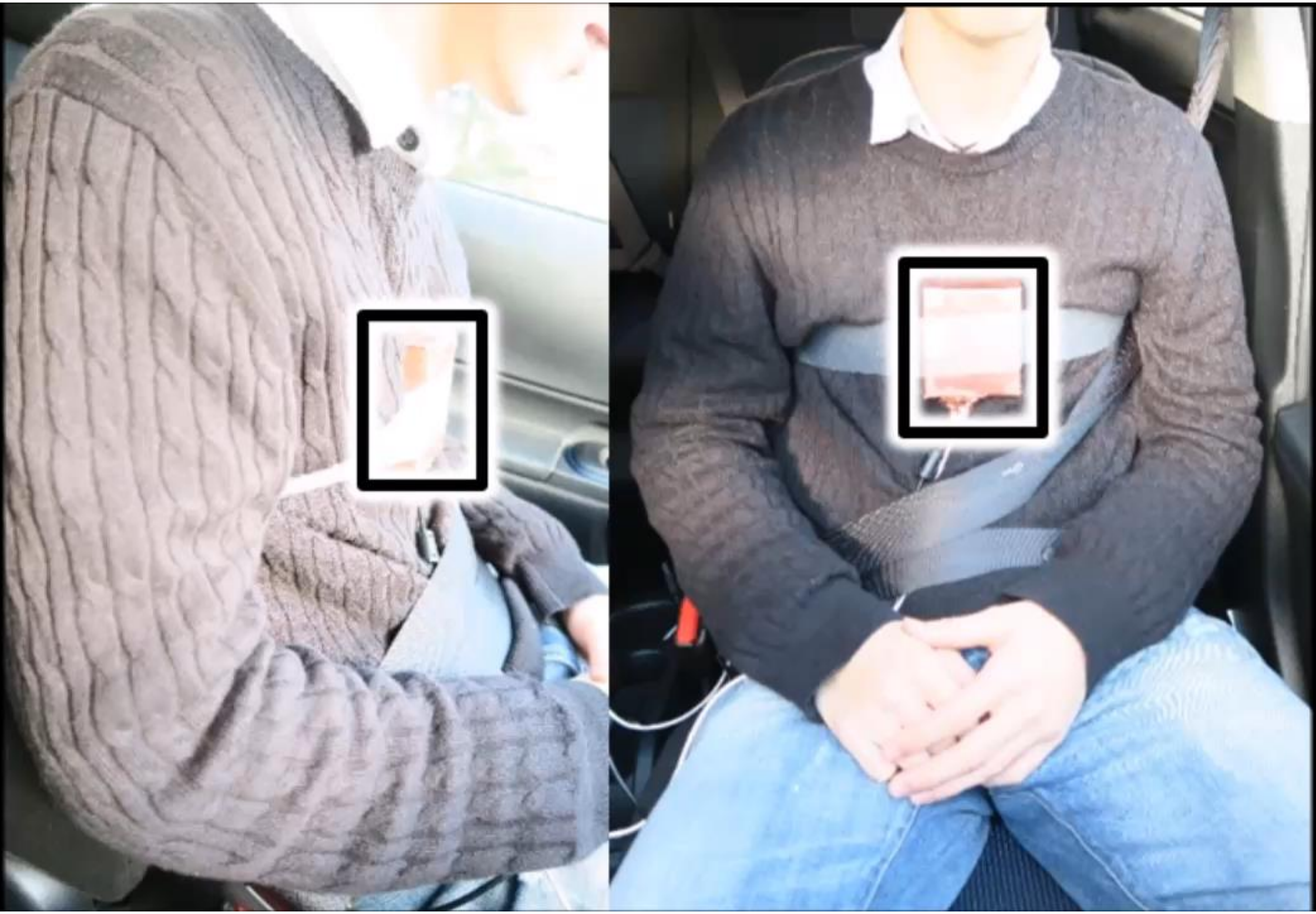
Driving speed < 50km/h

@R43, Kobe, Japan

w/ TOYOTA AQUA

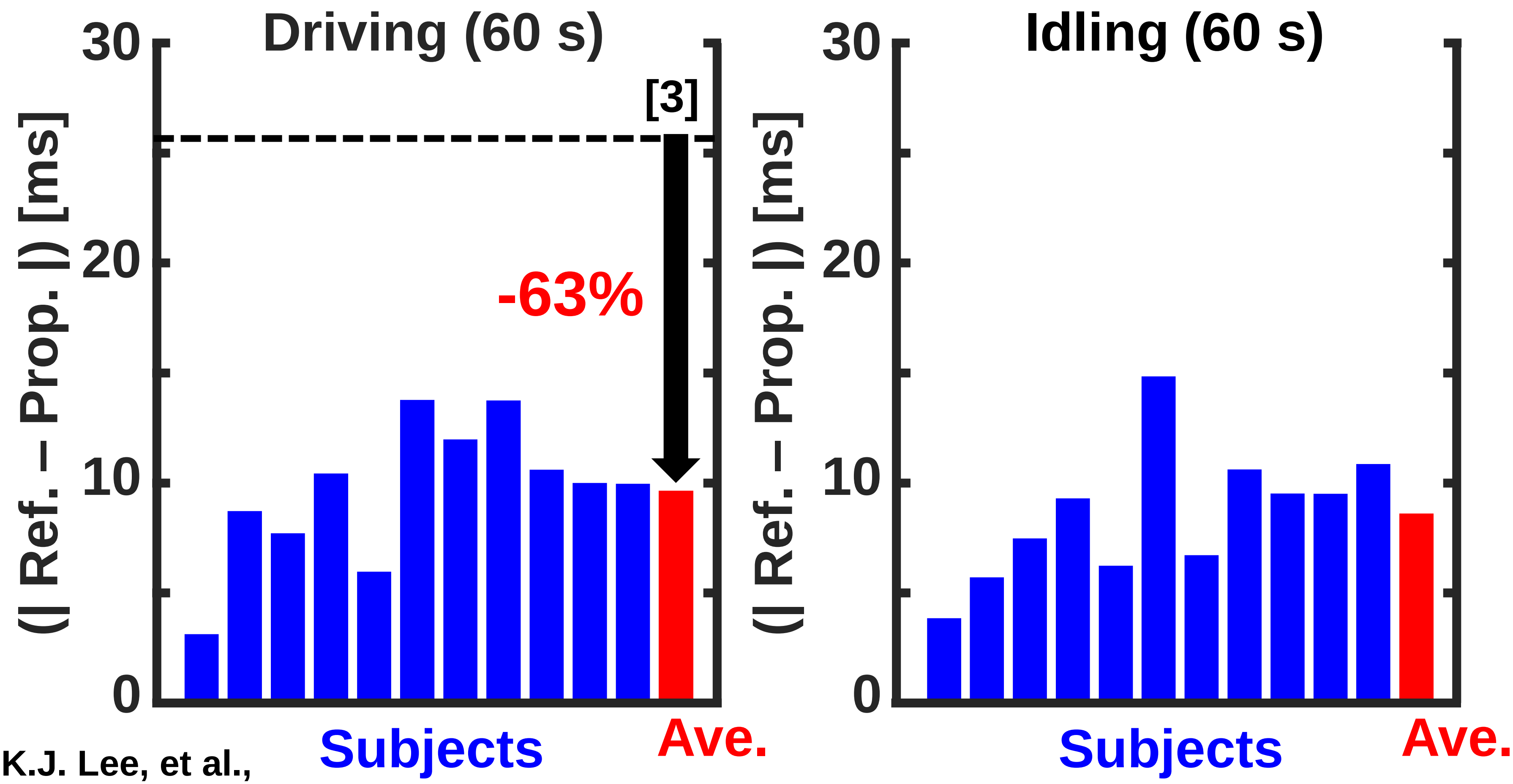
The sensor will be integrated with a

Microwave Doppler sensor



Accuracy of extracted HR

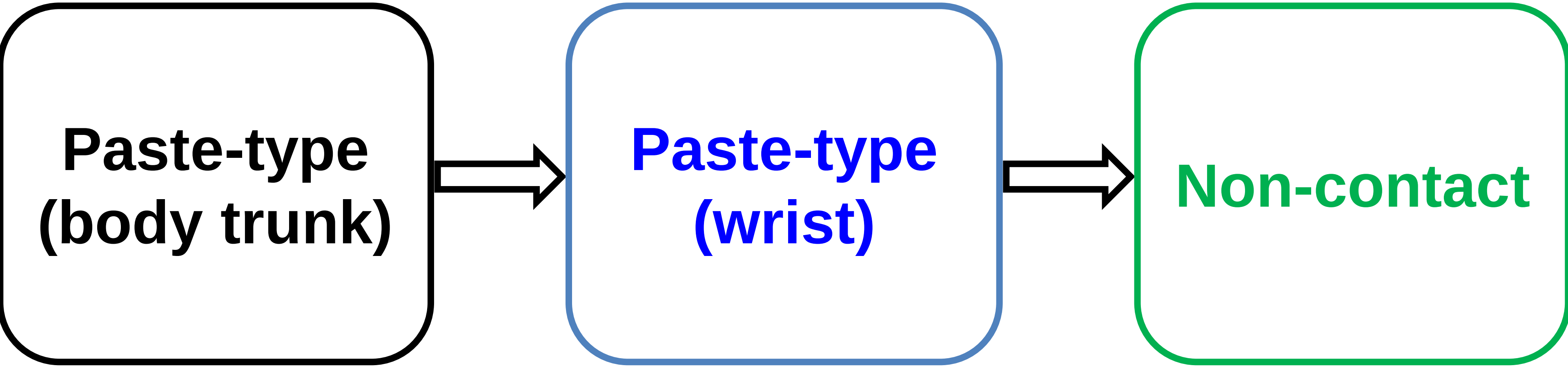
Mean absolute error of heart beat inteval



[3] K.J. Lee, et al., *EMBC 2016*, pp. 5417-5420, Aug. 2016.

Now, error is less than 10 ms.

Conclusion



1) Ultra-low-power pulse wave (PPG) sensor
   22 μA with 5-ms error is achieved.
2) Capacitively coupled ECG sensor
   ECG is measured in a room and in a car.
3) Microwave Doppler (heartbeat) sensor
   10-ms error is achieved while driving.