Wearable Photoplethysmography: The road ahead

Dr Peter H. Charlton
Dr Xiao Hu

The 2023 wearable photoplethysmography roadmap
https://doi.org/10.1088/1361-6579/acead2

Source:
https://negativespace.co/car-road-mountains/ (CC0)

Schedule

1. Wearable Photoplethysmography: Current Status and Future Challenges
   Peter H. Charlton, University of Cambridge, UK

2. Using wearable photoplethysmography for detecting atrial fibrillation in ambulatory conditions
   Antti Vehkaoja, Tampere University, Finland

3. Learning from alarms: A novel robust learning approach to learn an accurate photoplethysmography-based atrial fibrillation detector using eight million samples labeled with imprecise arrhythmia alarms
   Amit Shah, Emory University

4. Robust peak detection for photoplethysmography signal analysis
   Márton Áron Goda, Technion IIT, Israel

5. Discussion: How do we make the most of wearable photoplethysmography?
   All

Wearable Photoplethysmography: Current Status and Future Challenges

Dr Peter H. Charlton

University of Cambridge

City, University of London

Disclosures

The following presentation focuses on what is (in my view) an exciting article published in *Physiological Measurement*:

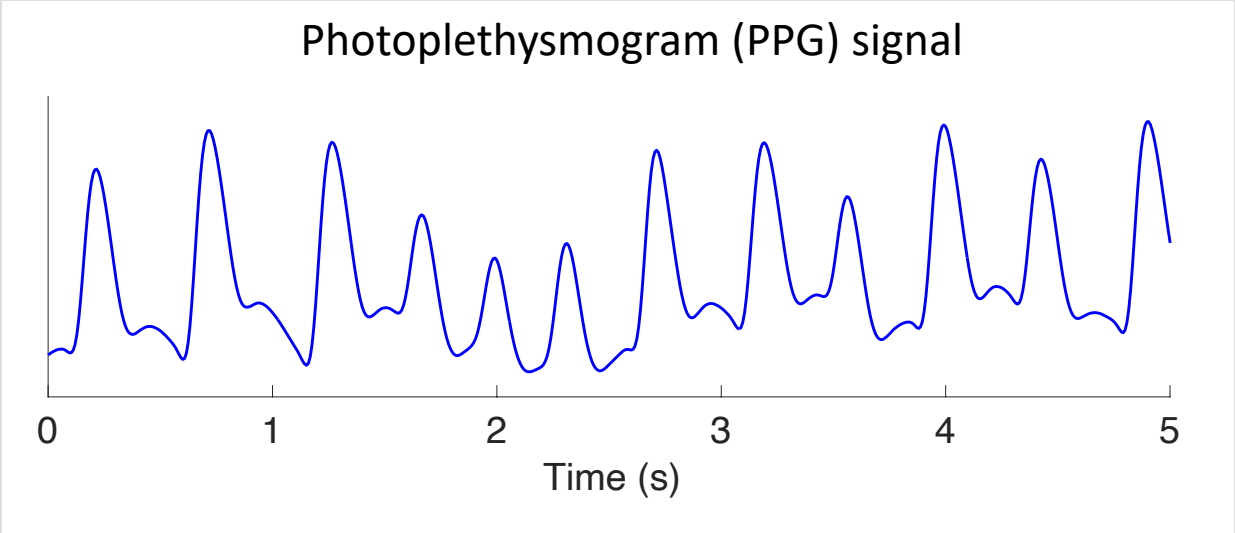
Charlton P.H. *et al.*, **The 2023 wearable photoplethysmography roadmap**, *Phys Meas*, 2023, https://doi.org/10.1088/1361-6579/acead2

Please note:

- I am on the Executive Editorial Board for *Physiological Measurement*
  (which has been a very interesting experience, I'd recommend it)

- My conference fee for Computing in Cardiology 2023 was paid by *IOP Publishing*, the publisher of *Physiological Measurement*.
  (for which I'm grateful)

Miyasaka *et al.*, https://doi.org/10.1007/s00540-021-02967-z (CC BY 4.0)




St. Thomas' Hospital
St. Thomas' Hospital

(artistic license – this heart rate is fictional)

Physiological Measurement

IPEM
Institute of Physics and Engineering in Medicine

TOPICAL REVIEW

The 2023 wearable photoplethysmography roadmap

Peter H Charlton[1,2,48], John Allen[3,4,48], Raquel Bailón[5,6,48], Stephanie Baker[7,48], Joachim A Behar[8], Fei Chen[9], Gari D Clifford[10,11,48], David A Clifton[12], Harry J Davies[13,48], Cheng Ding[14,15,48], Xiaorong Ding[16,48], Jessilyn Dunn[17,18,19,48], Mohamed Elgendi[20], Munia Ferdoushi[21,22,48], Daniel Franklin[23], Eduardo Gil[5,6], Md Farhad Hassan[21,22], Jussi Hernesniemi[24,25], Xiao Hu[26,27,28], Nan Ji[29], Yasser Khan[21,22], Spyridon Kontaxis[5,6], Ilkka Korhonen[24,48], Panicos A Kyriacou[2,48], Pablo Laguna[5,6], Jesús Lázaro[5,6], Chungkeun Lee[30], Jeremy Levy[8,31,48], Yumin Li[32], Chengyu Liu[32,48], Jing Liu[33,48], Lei Lu[12], Danilo P Mandic[13], Vaidotas Marozas[34,35,48], Elisa Mejía-Mejía[2,48], Ramakrishna Mukkamala[36,48], Meir Nitzan[37], Tania Pereira[38,39], Carmen C Y Poon[40,48], Jessica C Ramella-Roman[41,48], Harri Saarinen[25], Md Mobashir Hasan Shandhi[17], Hangsik Shin[42,48], Gerard Stansby[4,43], Toshiyo Tamura[44,48], Antti Vehkaoja[24,45,48], Will Ke Wang[17], Yuan-Ting Zhang[29,46], Ni Zhao[47], Dingchang Zheng[3] and Tingting Zhu[12,48]

https://doi.org/10.1088/1361-6579/acead2

Wearable Photoplethysmography

Findings of the Roadmap (and behind the scenes)

Opportunities

Luke Chesser, https://commons.wikimedia.org/wiki/File:Apple_Watch_user_(Unsplash).jpg (CC0 1.0)

Mehedi Hasan, https://unsplash.com/photos/_jFTWvKrwyY (Unsplash Licence)

Ilya Pavlov, unsplash.com/photos/OqtafYT5kTw (Unsplash Licence)

Wearable Photoplethysmography

Findings of the Roadmap (and behind the scenes)

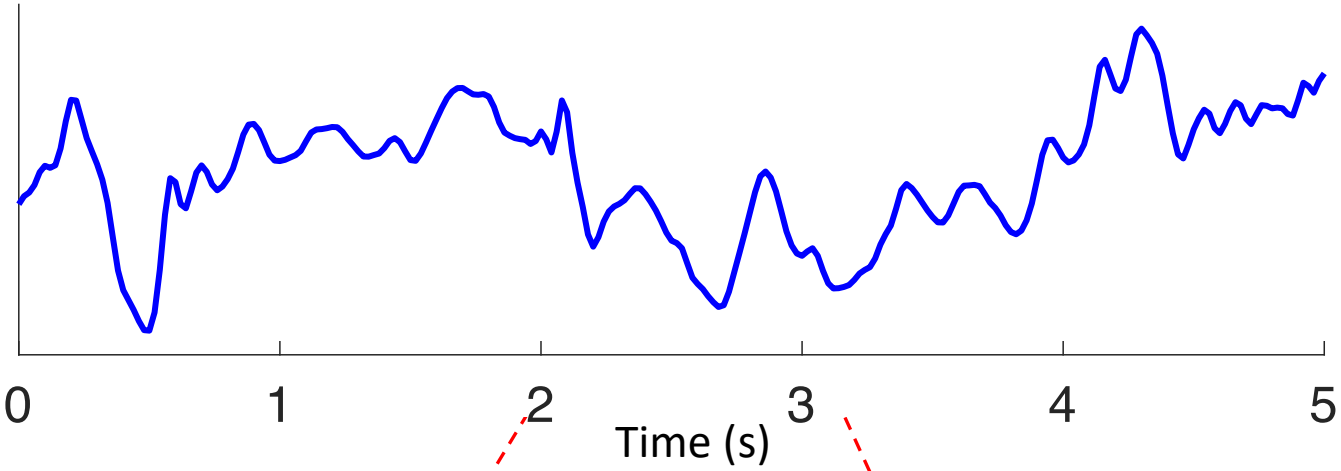
Opportunities

Luke Chesser, https://commons.wikimedia.org/wiki/File:Apple_Watch_user_(Unsplash).jpg (CC0 1.0)

Mehedi Hasan, https://unsplash.com/photos/_jFTWvKrwyY (Unsplash Licence)

Ilya Pavlov, unsplash.com/photos/OqtafYT5kTw (Unsplash Licence)

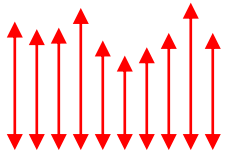
Photoplethysmogram (PPG)

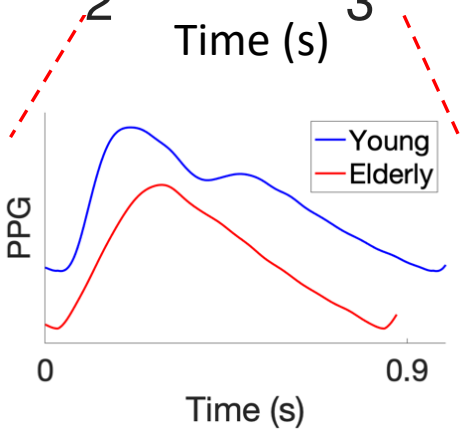


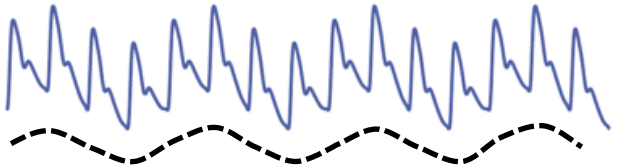
?
bpm

Normal rhythm

Arrhythmia







M. Verch, flickr, https://flickr.com/photos/160866001@N07/32586534637/ (CC BY 2.0)

Crew, Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Apple_Watch_user_(Unsplash).jpg (CC0 1.0)

Wearable Photoplethysmography

Findings of the Roadmap (and behind the scenes)

Opportunities

Luke Chesser, https://commons.wikimedia.org/wiki/File:Apple_Watch_user_(Unsplash).jpg (CC0 1.0)

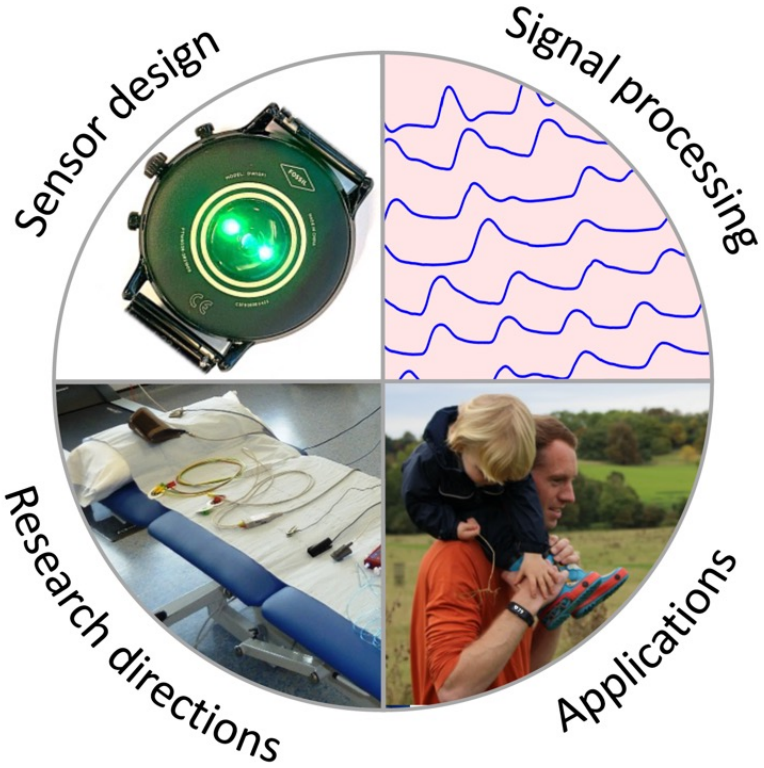
(Unsplash Licence)

Ilya Pavlov, unsplash.com/photos/OqtafYT5kTw (Unsplash Licence)

The 2023 wearable photoplethysmography roadmap

Aim: To provide key directions for research and development to realise the full potential of wearable photoplethysmography.

Methods: 51 experts provided their perspectives on 24 key topics within four areas:



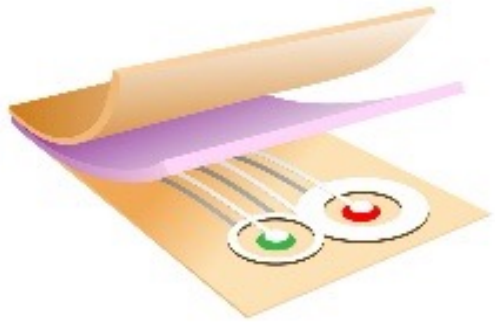
Source: Charlton PH *et al*., The 2023 wearable photoplethysmography roadmap, https://doi.org/10.1088/1361-6579/acead2 (CC BY 4.0)

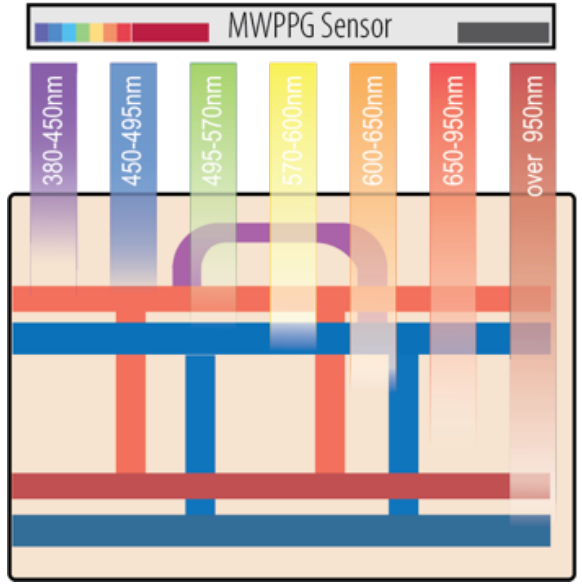
SENSOR DESIGN

Photoplethysmography with emerging materials and sensors

In-ear photoplethysmography for respiratory monitoring

Wearable multi-wavelength photoplethysmography





SENSOR DESIGN

Photoplethysmography with emerging materials and sensors

In-ear photoplethysmography for respiratory monitoring

Wearable multi-wavelength photoplethysmography

SIGNAL PROCESSING

Pulse rate variability

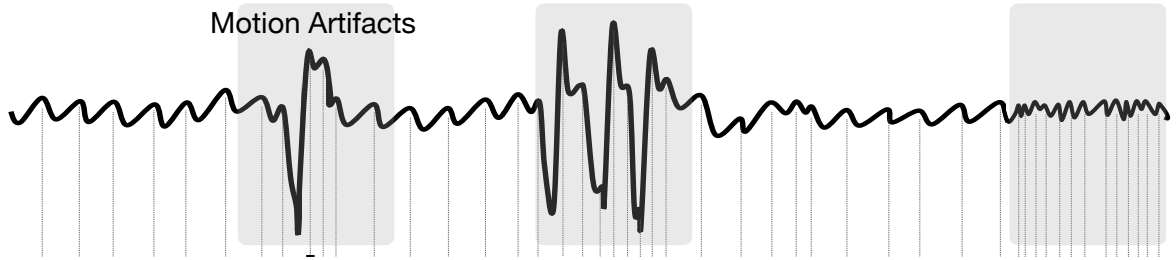
Respiratory monitoring

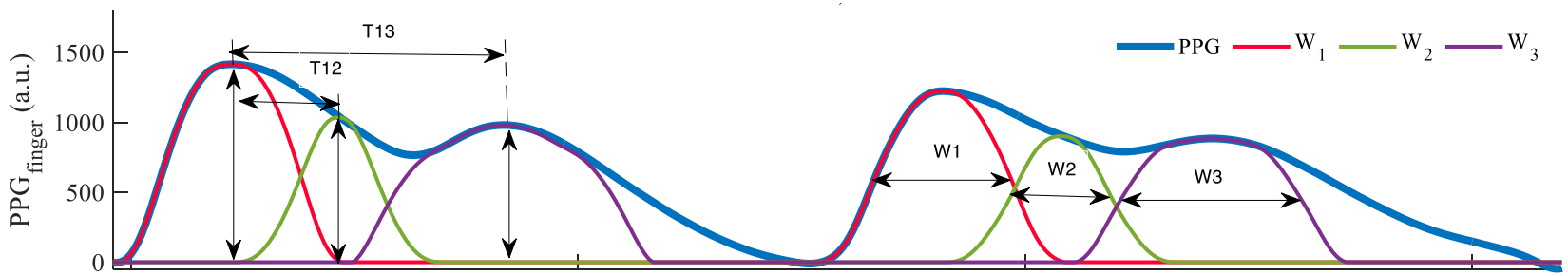
Pulse wave analysis

Development of wearable pulse oximeters

PPG signal quality: not a black and white matter

Motion artifacts in wearable photoplethysmography





SENSOR DESIGN

Photoplethysmography with emerging materials and sensors

In-ear photoplethysmography for respiratory monitoring

Wearable multi-wavelength photoplethysmography

SIGNAL PROCESSING

Pulse rate variability

Respiratory monitoring

Pulse wave analysis

Development of wearable pulse oximeters

PPG signal quality: not a black and white matter

Motion artifacts in wearable photoplethysmography

APPLICATIONS

Consumer applications

Detecting cardiac arrhythmias

Sleep assessment from the PPG

Diagnosing obstructive sleep apnea from pulse oximetry

Mental health assessment by autonomic nervous system monitoring

Unobtrusive and continuous blood pressure monitoring

Hospital monitoring

PPG low frequency variability and autonomic function

Assessment of vascular age and arterial compliance

Assessment of peripheral arterial disease

RESEARCH DIRECTIONS

Investigating waveform analysis for blood pressure monitoring

Sources of inaccuracy in wearable photoplethysmography

Wearable data analysis

Understanding the origins of the photoplethysmogram

Alternatives to photoplethysmography

Source: Charlton PH *et al.*, The 2023 wearable photoplethysmography roadmap, https://doi.org/10.1088/1361-6579/acead2 (CC BY 4.0)

SENSOR DESIGN

Photoplethysmography with emerging materials and sensors

In-ear photoplethysmography for respiratory monitoring

Wearable multi-wavelength photoplethysmography

SIGNAL PROCESSING

Pulse rate variability

Respiratory monitoring

Pulse wave analysis

Development of wearable pulse oximeters

PPG signal quality: not a black and white matter

Motion artifacts in wearable photoplethysmography

APPLICATIONS

Consumer applications

Detecting cardiac arrhythmias

Sleep assessment from the PPG

Diagnosing obstructive sleep apnea from pulse oximetry

Mental health assessment by autonomic nervous system monitoring

Unobtrusive and continuous blood pressure monitoring

Hospital monitoring

PPG low frequency variability and autonomic function

Assessment of vascular age and arterial compliance

Assessment of peripheral arterial disease

RESEARCH DIRECTIONS

Investigating waveform analysis for blood pressure monitoring

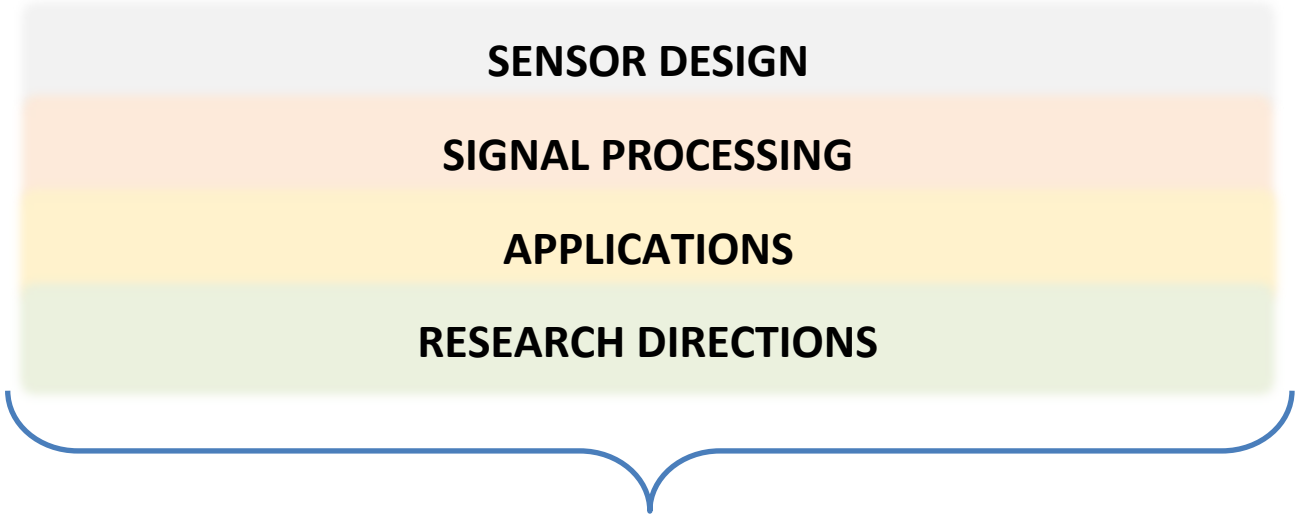
Sources of inaccuracy in wearable photoplethysmography

Wearable data analysis

Understanding the origins of the photoplethysmogram

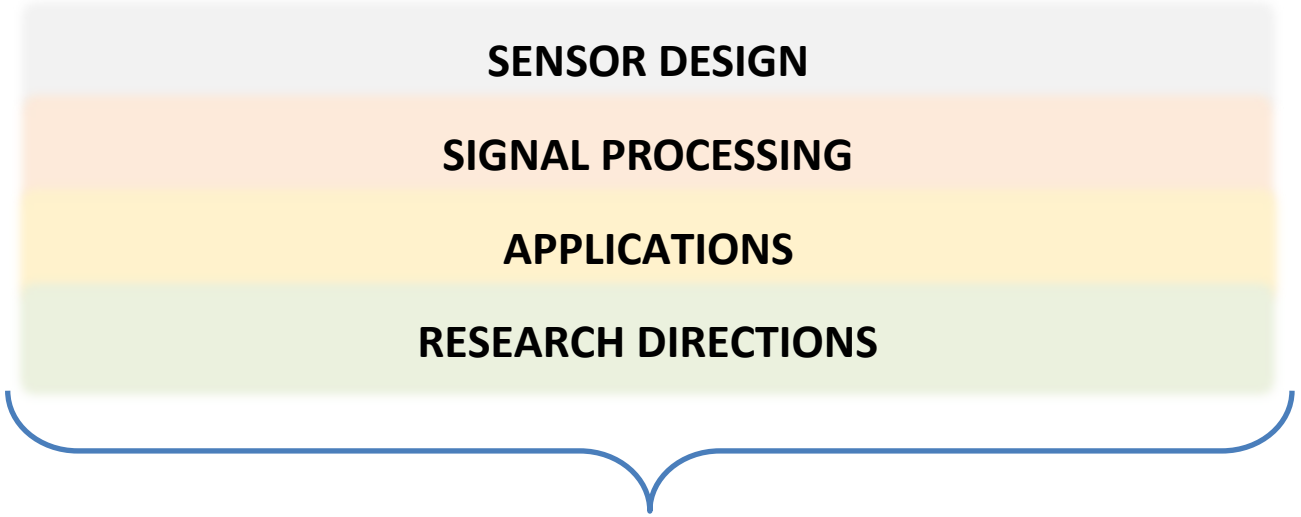
Alternatives to photoplethysmography

Source: Charlton PH *et al.*, The 2023 wearable photoplethysmography roadmap, https://doi.org/10.1088/1361-6579/acead2 (CC BY 4.0)



Themes emerging

- Expanding functionality
- Optimising sensor design
- Approaches to signal processing
- Identifying potential applications
- Gaining trust



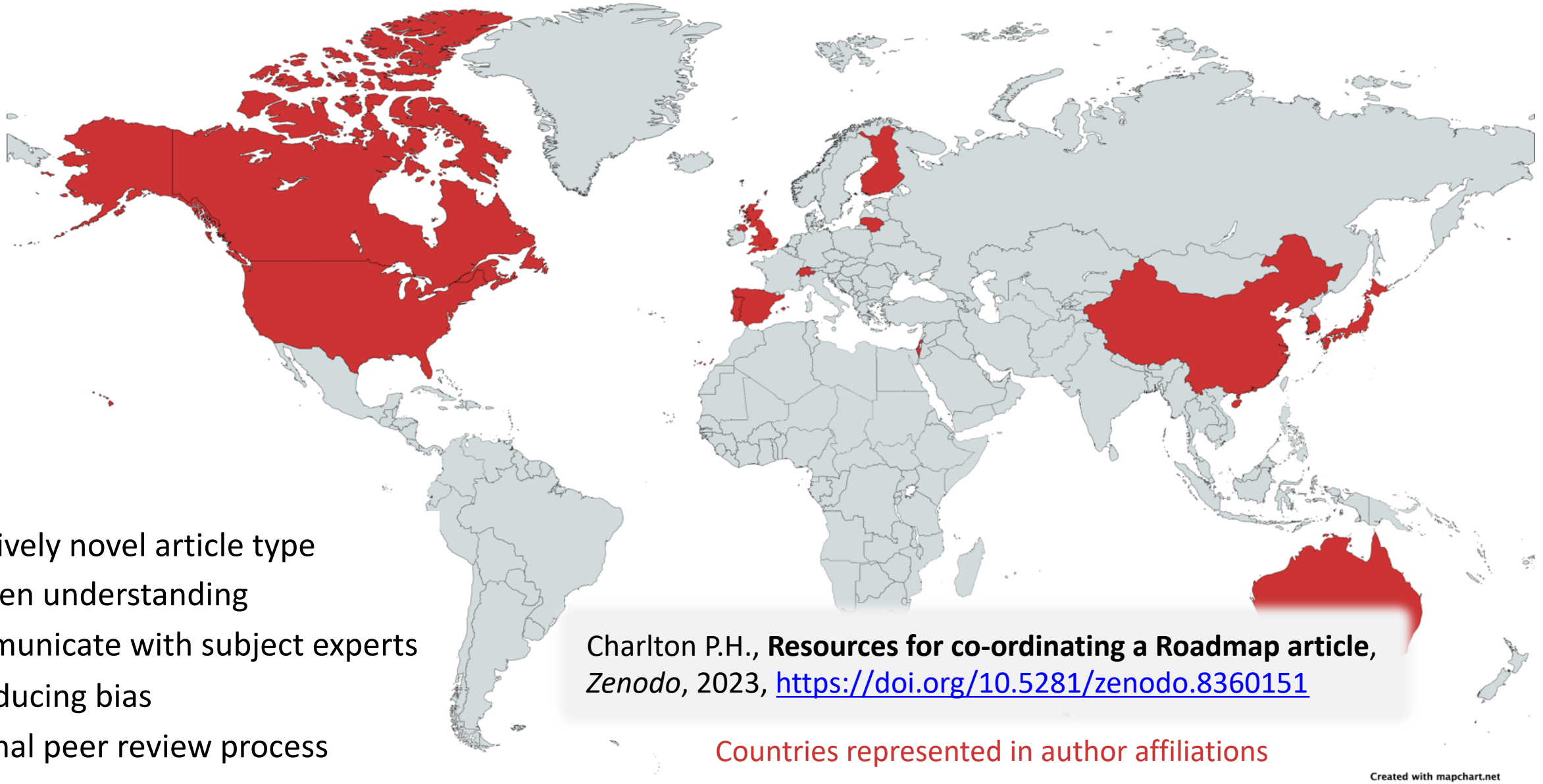
Themes emerging

- Expanding functionality
- Optimising sensor design
- Approaches to signal processing
- Identifying potential applications
- Gaining trust

Challenges and solutions

- Signal quality
- Signal processing resources
- Device validation
- Sources of inaccuracy
- Equity
- Best practices

Co-ordinating a Roadmap article



- Relatively novel article type
- Deepen understanding
- Communicate with subject experts
- Introducing bias
- Internal peer review process

Charlton P.H., **Resources for co-ordinating a Roadmap article**, *Zenodo*, 2023, https://doi.org/10.5281/zenodo.8360151

Wearable Photoplethysmography

Findings of the Roadmap (and behind the scenes)

Opportunities

Luke Chesser, https://commons.wikimedia.org/wiki/File:Apple_Watch_user_(Unsplash).jpg (CC0 1.0)

(Unsplash Licence)

Ilya Pavlov, unsplash.com/photos/OqtafYT5kTw (Unsplash Licence)

Opportunities

Focus Collection in *Physiological Measurement* on:

Open Source and Validated Computational Tools for Physiological Time Series Analysis

https://iopscience.iop.org/collections/pmea-230825-336

pyPPG:

A new toolbox for PPG analysis

https://pyppg.readthedocs.io/

Wearables network:

We're hoping to establish a (primarily European) network to collaborate on research into wearables

(ask me)

With thanks to…

Jonathan Mant — University of Cambridge

Panicos Kyriacou

British Heart Foundation

Innovate UK

VascAgeNet

The 50 co-authors of ‘The 2023 wearable photoplethysmography roadmap’, who have been a joy to work with.

Physiological Measurement

IPEM
Institute of Physics and Engineering in Medicine

TOPICAL REVIEW

The 2023 wearable photoplethysmography roadmap

Peter H Charlton[1,2,48], John Allen[3,4,48], Raquel Bailón[5,6,48], Stephanie Baker[7,48], Joachim A Behar[8], Fei Chen[9], Gari D Clifford[10,11,48], David A Clifton[12], Harry J Davies[13,48], Cheng Ding[14,15,48], Xiaorong Ding[16,48], Jessilyn Dunn[17,18,19,48], Mohamed Elgendi[20], Munia Ferdoushi[21,22,48], Daniel Franklin[23], Eduardo Gil[5,6], Md Farhad Hassan[21,22], Jussi Hernesniemi[24,25], Xiao Hu[26,27,28], Nan Ji[29], Yasser Khan[21,22], Spyridon Kontaxis[5,6], Ilkka Korhonen[24,48], Panicos A Kyriacou[2,48], Pablo Laguna[5,6], Jesús Lázaro[5,6], Chungkeun Lee[30], Jeremy Levy[8,31,48], Yumin Li[32], Chengyu Liu[32,48], Jing Liu[33,48], Lei Lu[12], Danilo P Mandic[13], Vaidotas Marozas[34,35,48], Elisa Mejía-Mejía[2,48], Ramakrishna Mukkamala[36,48], Meir Nitzan[37], Tania Pereira[38,39], Carmen C Y Poon[40,48], Jessica C Ramella-Roman[41,48], Harri Saarinen[25], Md Mobashir Hasan Shandhi[17], Hangsik Shin[42,48], Gerard Stansby[4,43], Toshiyo Tamura[44,48], Antti Vehkaoja[24,45,48], Will Ke Wang[17], Yuan-Ting Zhang[29,46], Ni Zhao[47], Dingchang Zheng[3] and Tingting Zhu[12,48]

https://doi.org/10.1088/1361-6579/acead2

Wearable photoplethysmography has potential to provide a wealth of physiological information with numerous applications in health, fitness, and wellbeing.

However, there is much work to be done to realise the full potential of wearable photoplethysmography.

The ‘2023 Wearable Photoplethysmography Roadmap’ provides valuable directions for future work to help guide future research and development in the field.

Charlton P.H. *et al.*, **The 2023 wearable photoplethysmography roadmap**, *Phys Meas*, 2023, https://doi.org/10.1088/1361-6579/acead2

Wearable Photoplethysmography: Current Status and Future Challenges

Dr Peter H. Charlton

https://peterhcharlton.github.io

pc657@cam.ac.uk

Slides at:
https://doi.org/10.5281/zenodo.8392964

1. Wearable Photoplethysmography: Current Status and Future Challenges
   Peter H. Charlton, University of Cambridge, UK
2. Using wearable photoplethysmography for detecting atrial fibrillation in ambulatory conditions
   Antti Vehkaoja, Tampere University, Finland
3. Learning from alarms: A novel robust learning approach to learn an accurate photoplethysmography-based atrial fibrillation detector using eight million samples labeled with imprecise arrhythmia alarms
   Amit Shah, Emory University
4. Robust peak detection for photoplethysmography signal analysis
   Márton Áron Goda, Technion IIT, Israel
5. Discussion: What are the most important next steps for wearable photoplethysmography?
   All

How do we make the most of wearable photoplethysmography?

The 2023 wearable photoplethysmography roadmap
https://doi.org/10.1088/1361-6579/acead2

Source:
https://negativespace.co/car-road-mountains/ (CC0)