Energy Efficient Heart Rate Sensing using a Painted Electrode ECG Wearable

Christopher Beach

Authors: Sammy Krachunov, Christopher Beach, Alexander J. Casson, James Pope, Xenofon Fafoutis, Robert J. Piechocki and Ian Craddock

christopher.beach@manchester.ac.uk

www.eee.manchester.ac.uk/sisp

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Objectives

Overview IoT in healthcare initiatives in the UK and how we align with these

Motivate the need for and benefit of wearable sensors for IoT in healthcare

Demonstrate a wearable ECG unit with more than one month of battery life

Overarching motivation

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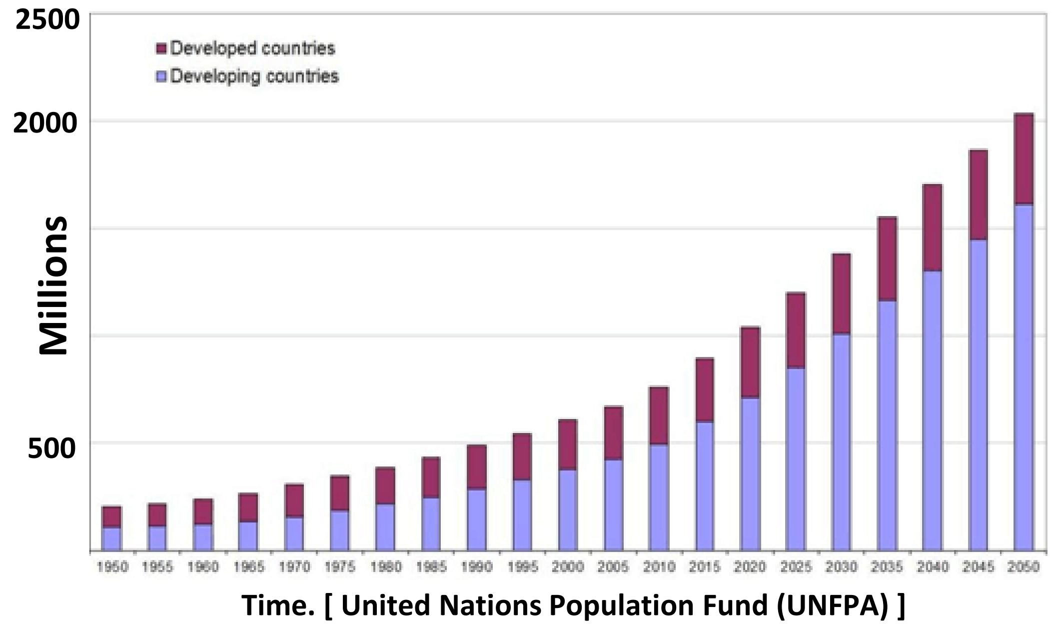
Ageing of the global population is unprecedented and the existing medical system will soon not be able to meet this increasing demand.

Therefore the use of emerging **digital technologies for healthcare monitoring** is essential.

Our aim is to impact a range of healthcare needs by employing data-fusion from a common platform of largely non-medical networked sensors in a home environment.



Number of people aged 60 or over is increasing exponentially

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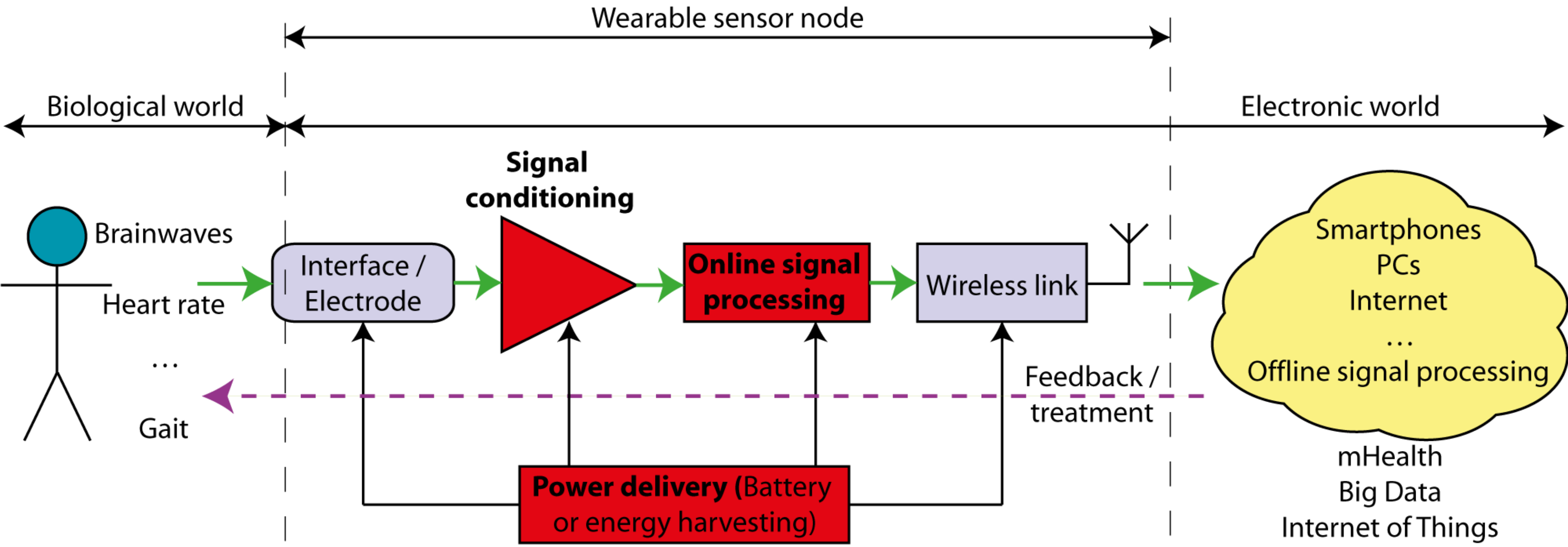
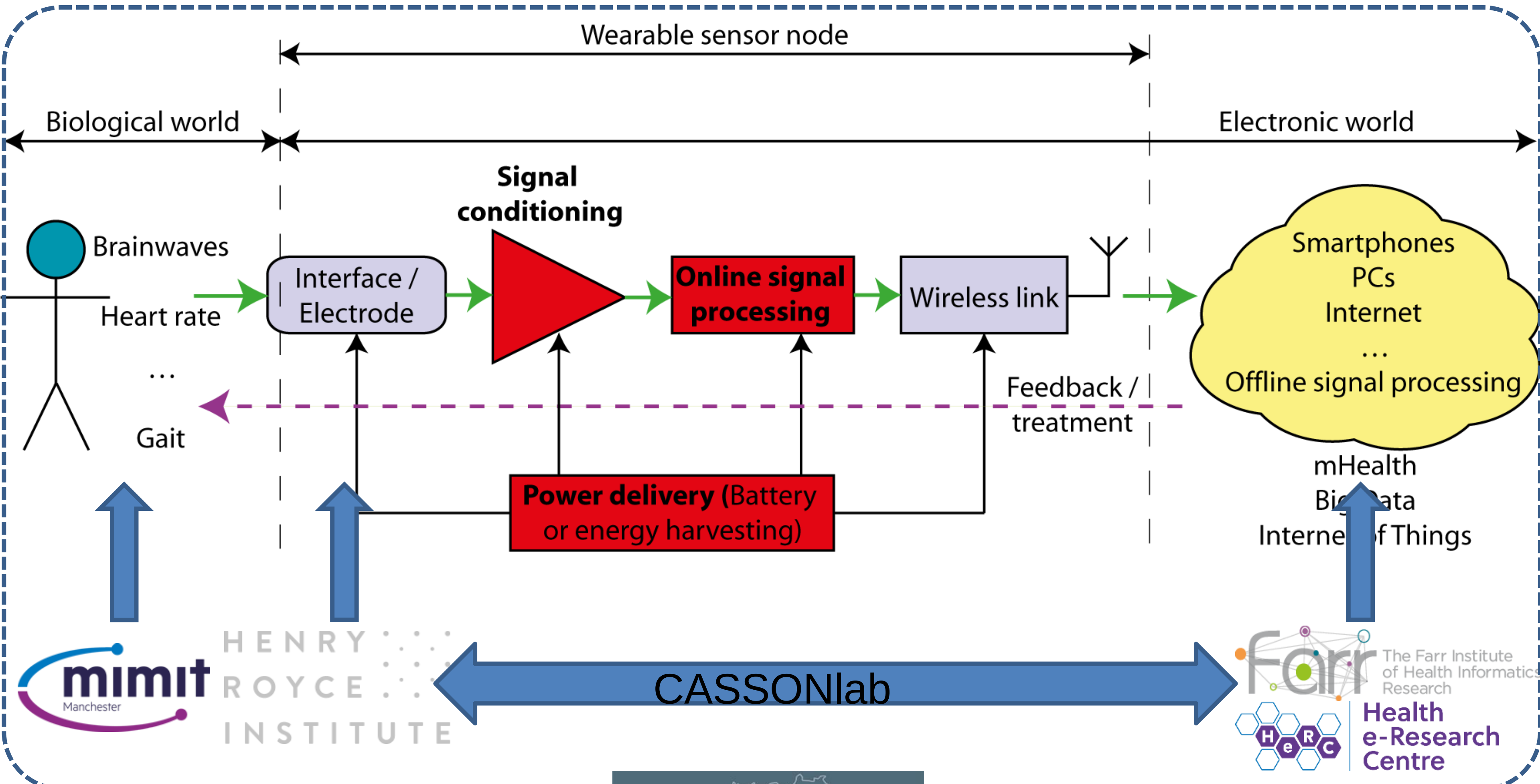
Our contribution: Smart sensors



Smart sensors in Manchester



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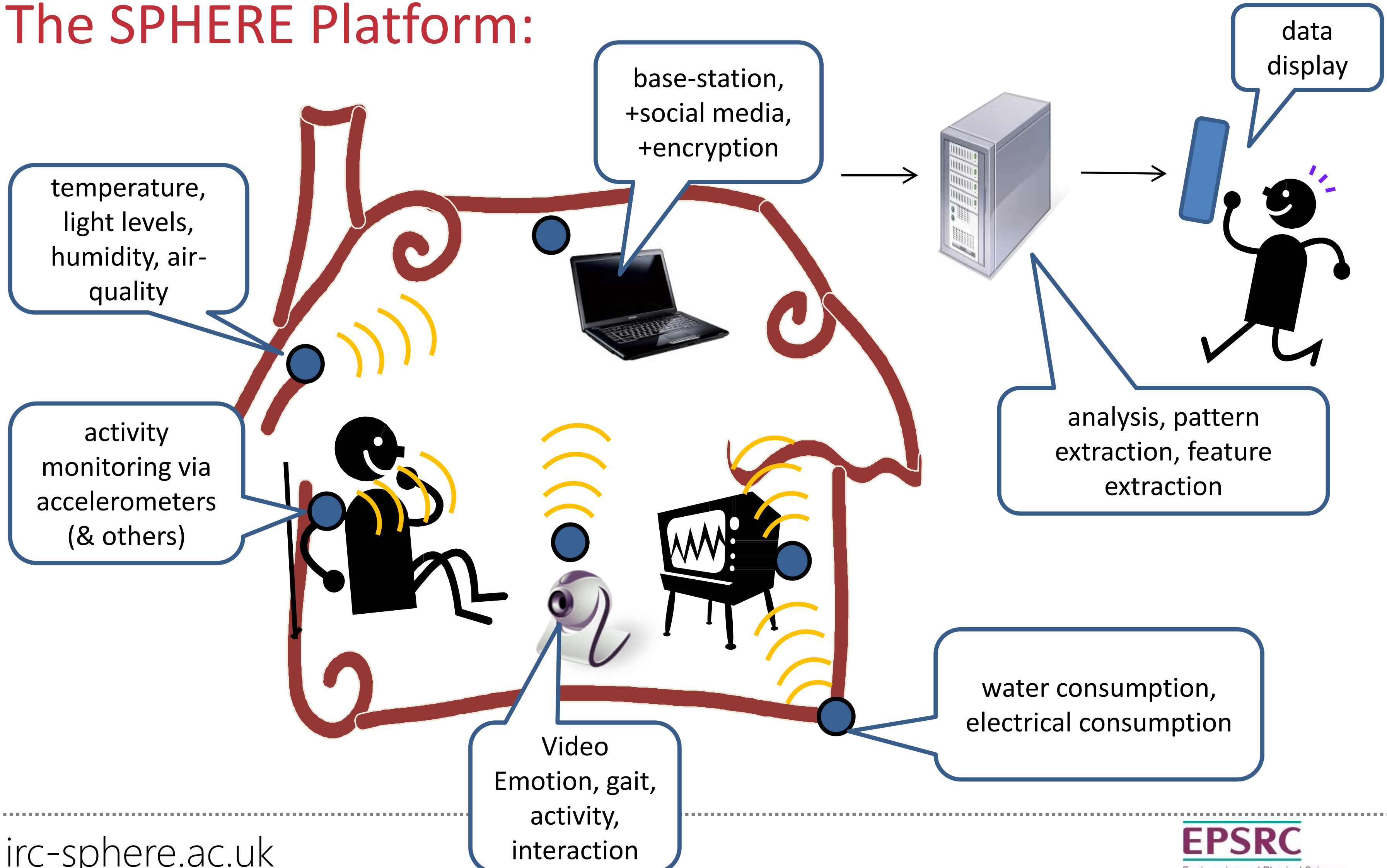
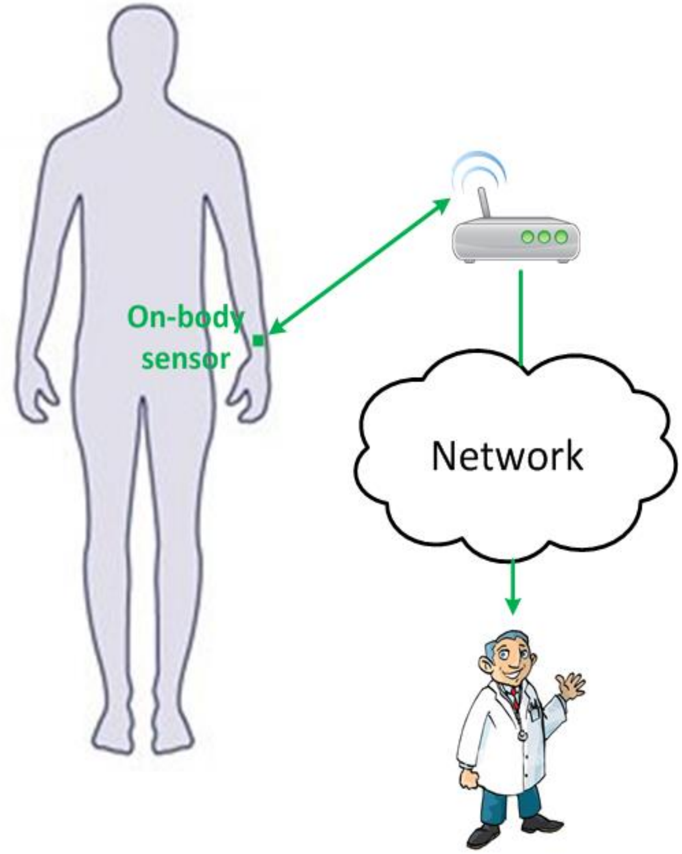
The SPHERE Platform:



On-body sensors

- Our vision is to develop a robust, energy efficient and user acceptable wireless communication system, consisting of:
    - one (or multiple) **on-body wearable sensor(s)** (e.g. accelerometer), and
    - an in-house **network of access points**.
- The system will provide real-time information regarding **physical activity** and **localisation**.
- The on-body node will ideally be powered using **energy harvesting** techniques.



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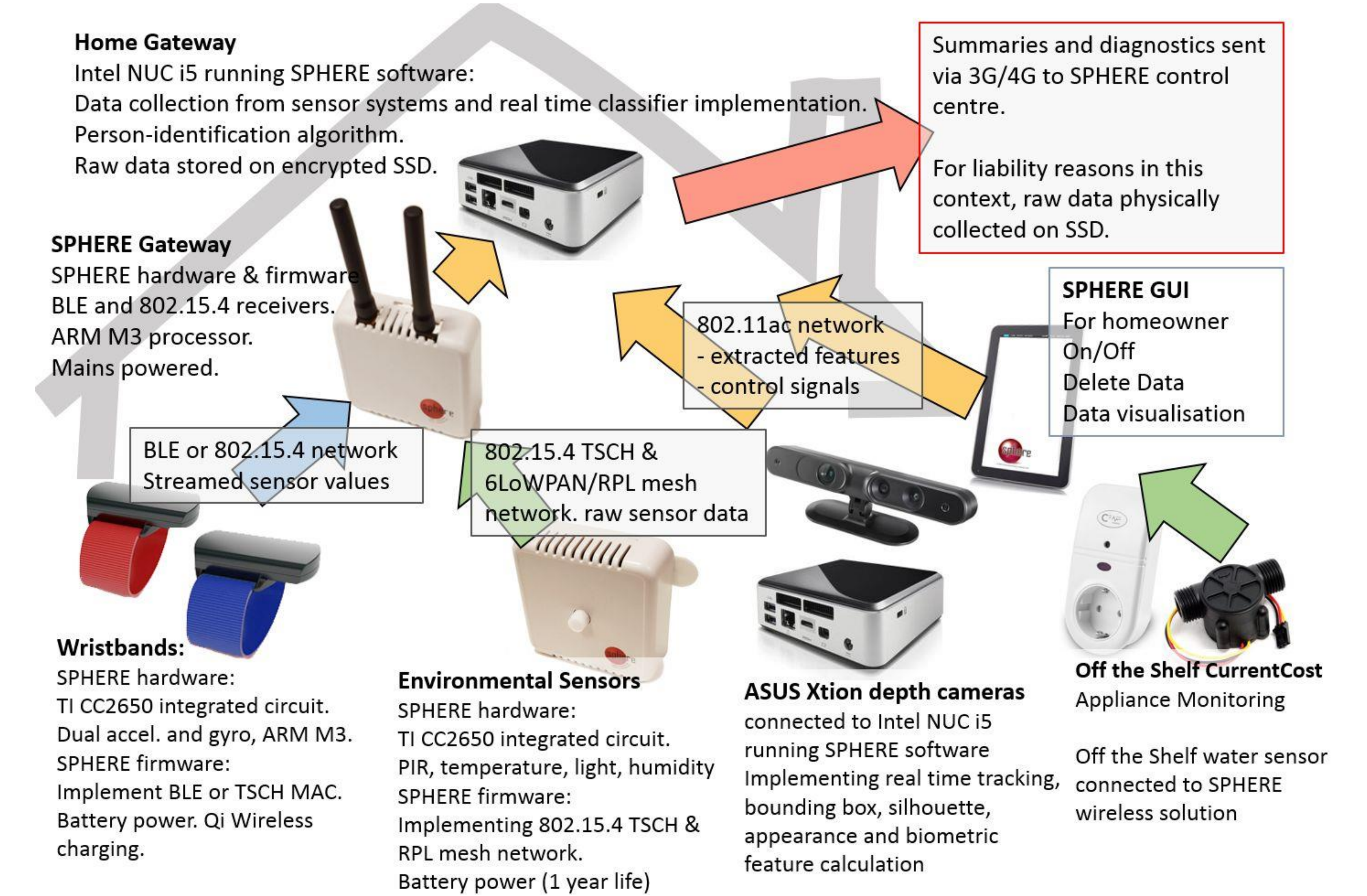
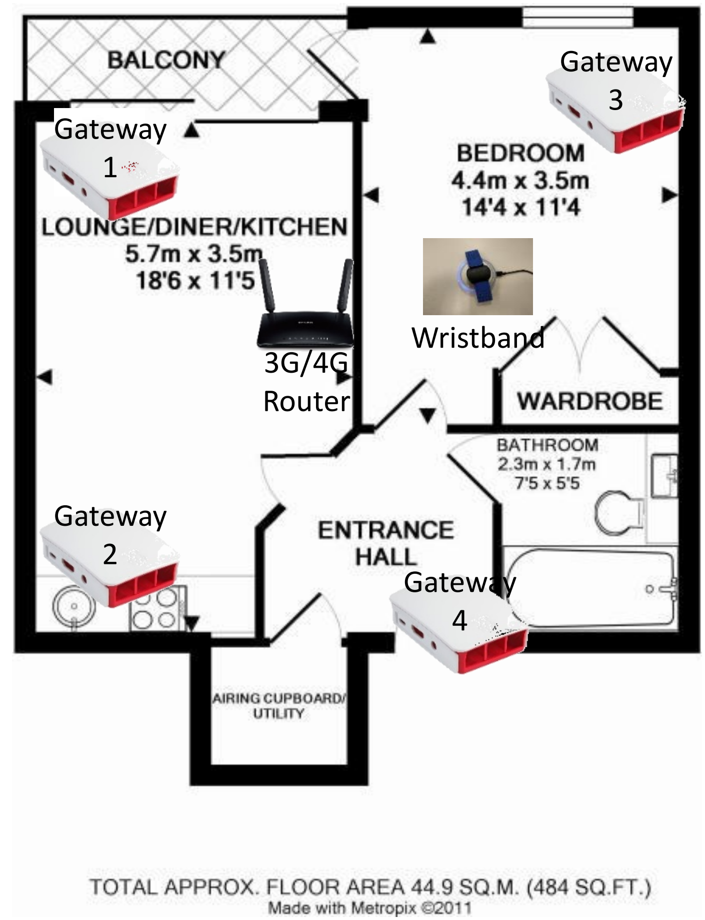


Example of SHERE IoT enabled house

- Items per system
  - 1 x **Router** 4G / 3G, WiFi
  - 4 x **Gateway** Raspberry Pi 3 (built in WiFi and BLE)
  - 1 x **Wristband** SPHERE (BLE, ADXL362, 4Gb FLASH)
- The Router and Gateways are fixed and the Wristband is worn by the participant
  - Charge when showering



Motivation for this work

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Want to integrate heart monitoring into this platform

PPG is common in smart watches, and great, but:

[TomTom]

- × High power due to light source.
- × Difficult to extract heart rate variability.
- × Less clinically relevant information than the ECG.
- × Not integrated with IoT infrastructure.

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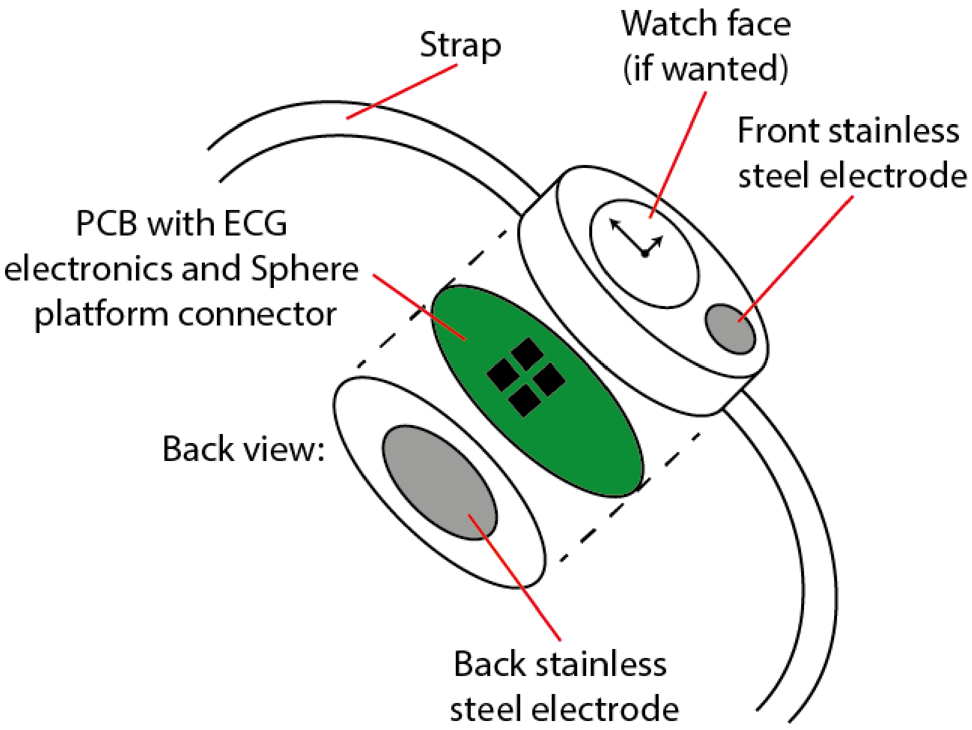
Our aim

We aim to make a wrist worn ECG device



- ✓ Lower power as no light source.
- ✓ Very light weight.
- ✓ ECG waveform allowing heart rate, heart variability, and other measures to be extracted.
- ✓ More healthcare relevant information than just PPG.
- ✓ Integrate with SPHERE IoT infrastructure.

Design requirements

Power:

1 month battery life

10 μW power consumption, 1.8 V supply

Data:

Ability to extract HR and HRV

Accuracy of a few BPM

Safety:

18 μA max fault current into user

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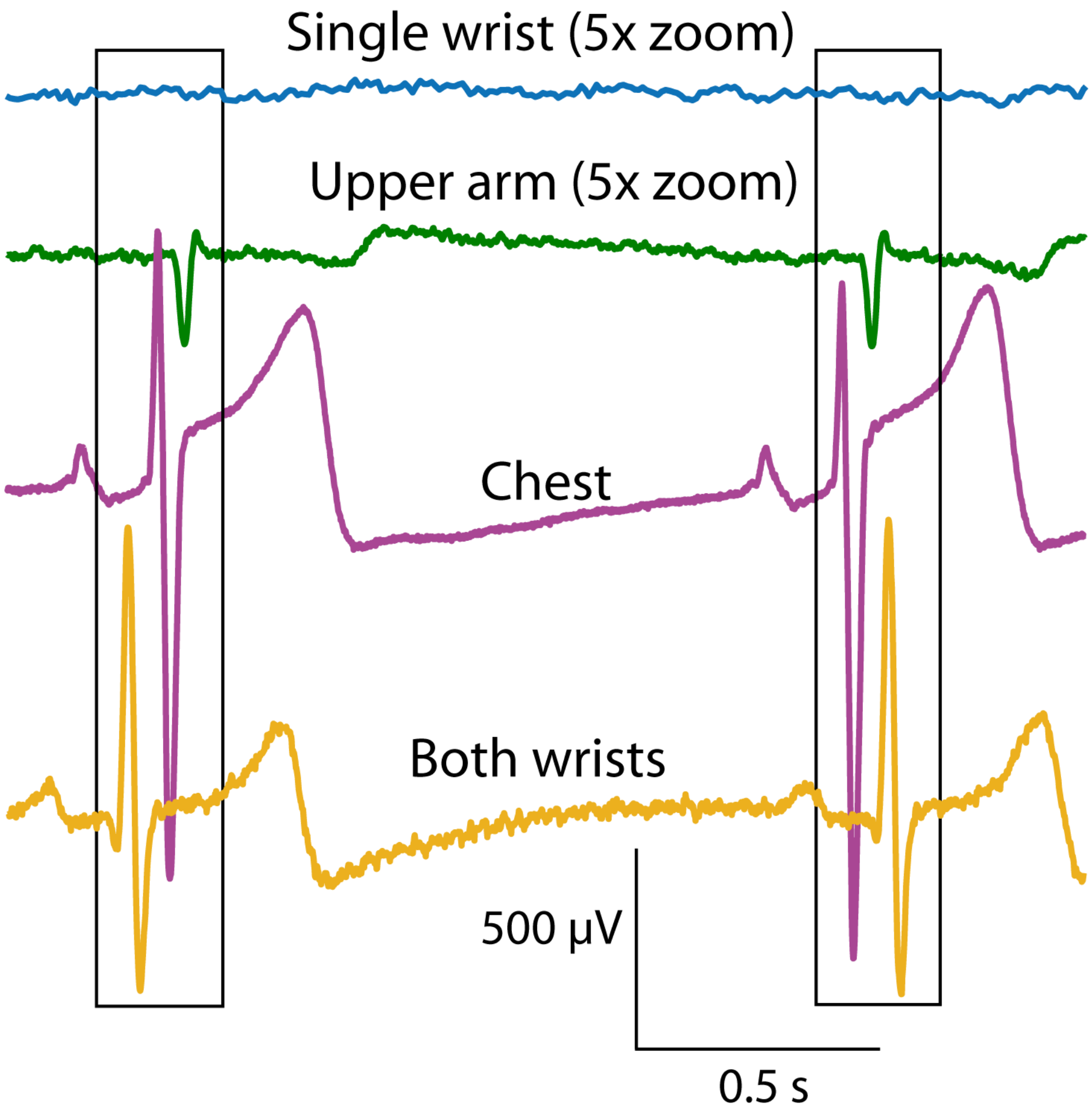
Challenge of wearable ECG



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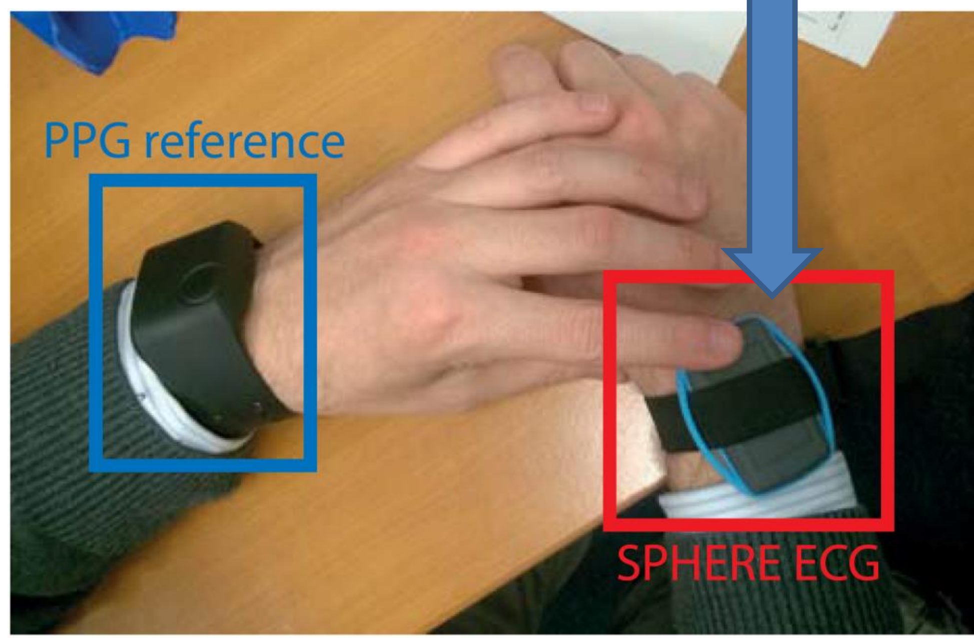
Final system

Painted electrode

SPHERE board ECG board

Electrodes on both sides of body to get large signal size



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Electrodes

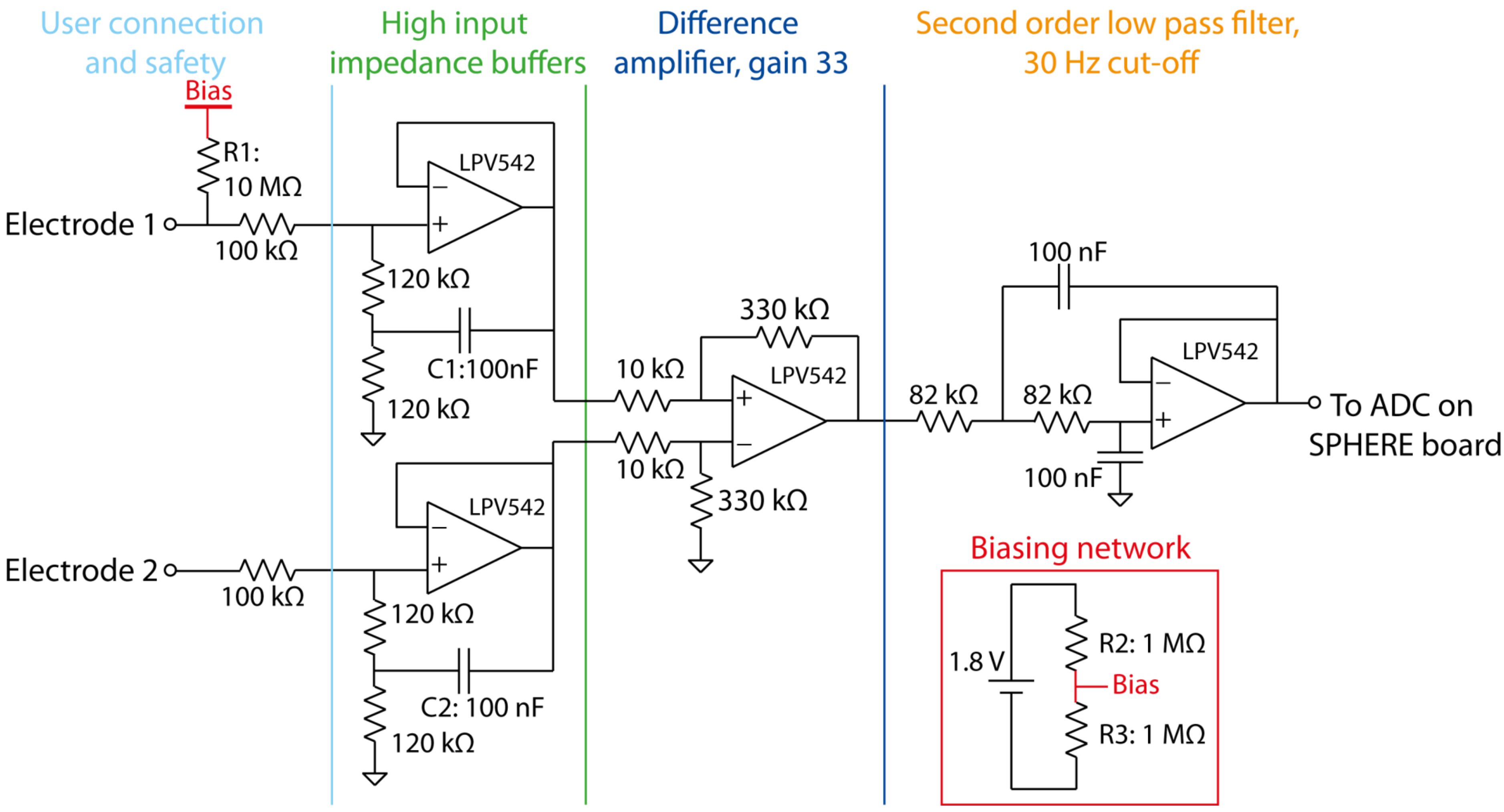
Medical grade Silver/Silver Chloride electrodes painted on

Allows size and shape personalisation

Painted electrode

3D print for more complicated shapes and personalisation

Front-end circuit design



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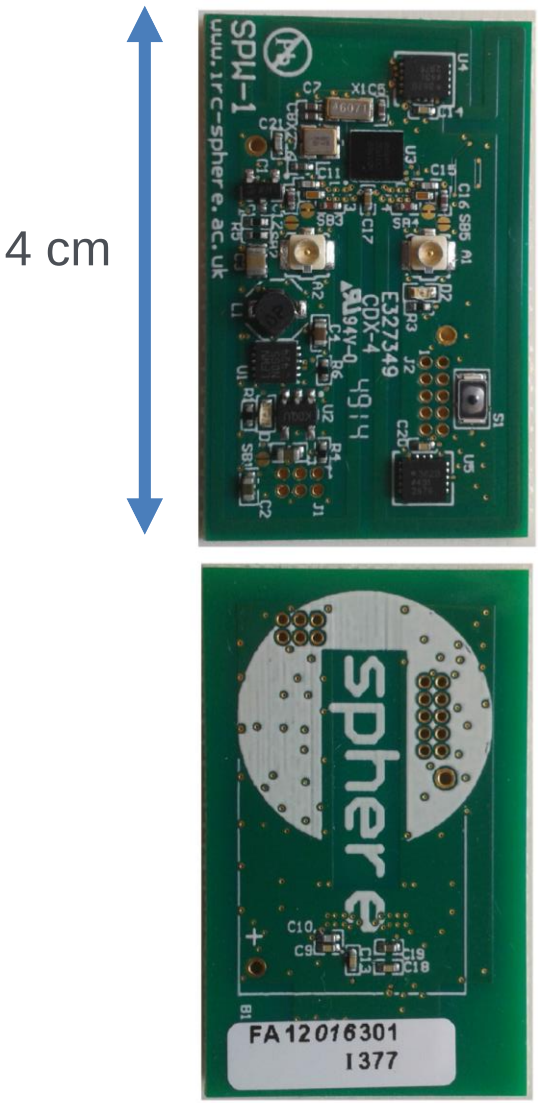
SPHERE wearable



- ✓ Based on TI CC2640
- ✓ Bluetooth low energy wireless transmission
- ✓ Local SD card memory
- ✓ 100 mAh rechargeable Li-ion battery
- ✓ Qi wireless charging
- ✓ ADXL 3-axis accelerometer

- ✓ We use the TI sensor controller for low power ADC and data storage without waking main MCU.

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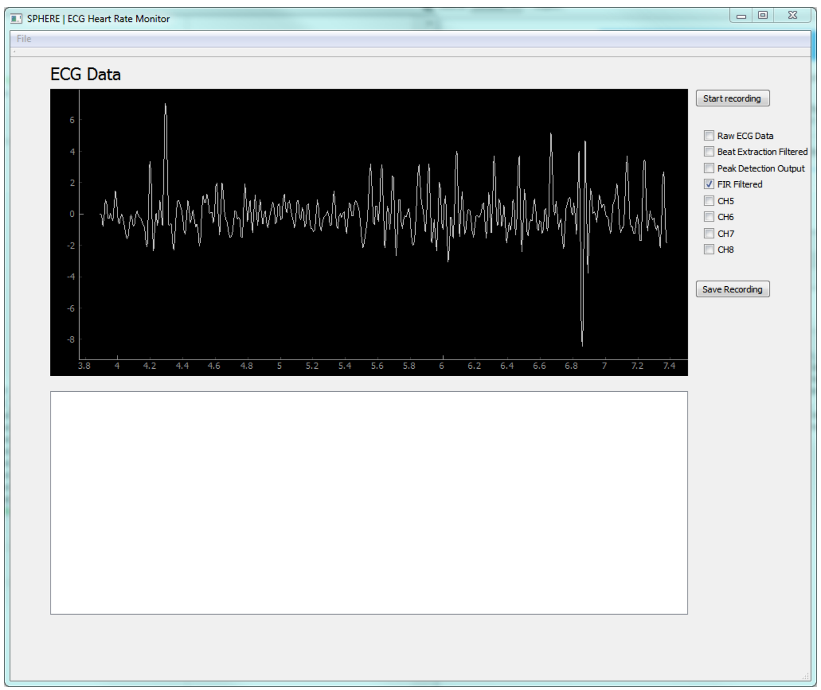
Software

Two options for communication

‘Connected’ state

- ✓ All data transmitted over BLE.
- ✓ Allows online and offline signal analysis in basestation.

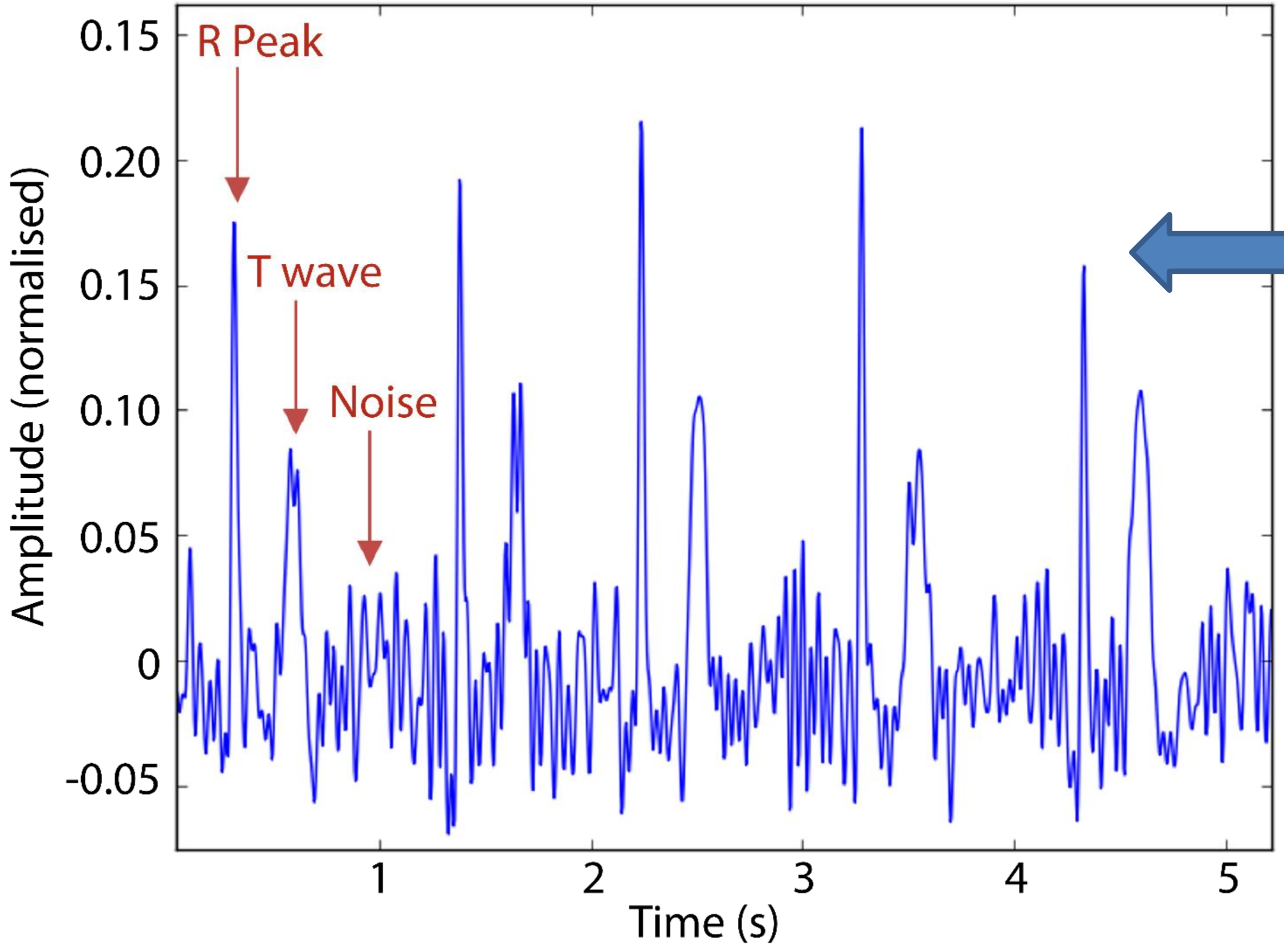


‘Not-connected’ state

- ✓ Heart rate calculated on the wearable.
- ✓ Just heart rate information transmitted.
- ✓ Low data rate means data can be included in the BLE advertising packets.
- ✓ Reduces power significantly if full ECG trace is not required.

System performance

Raw data shows clear heart beats



This is before standard ECG processing for noise removal

Deliberately high noise floor to keep power low

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Comparison to a reference PPG

Methods for offline comparison of data

1. Raw ECG data filtered: Butterworth first order low pass, highpass and notch
2. Baseline wander removed with Discrete Wavelet Transform
3. Noise removed from ECG using extended Kalman filter
4. Heart beats detected using standard Pan-Tompkins algorithm
5. Heart rate calculated from beat timings
6. Kalman tracking filter applies with zero-order-hold model to smooth heart rate when incorrect (missing and/or additional) beats detected

Compare heart rate to that from a commercial PPG device

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System performance

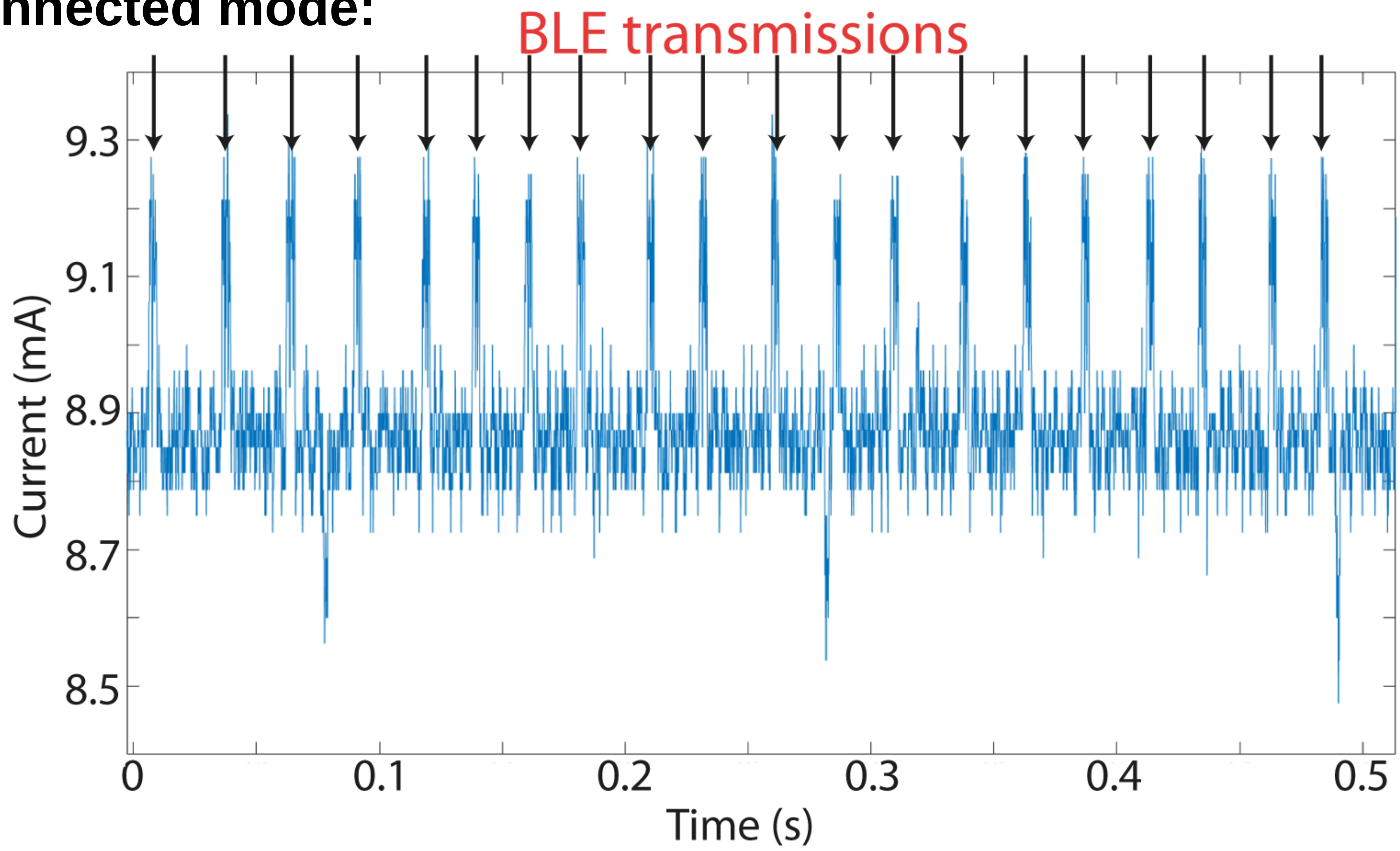
Accurate to within a few beats to minute

Record	Mean difference (BPM)	Standard deviation (BPM)
1	5.61	4.02
2	2.87	1.80
3	6.77	6.08
4	11.3	2.59
5	2.66	2.87
6	5.96	6.17
7	1.83	1.85
8	2.19	2.29
9	1.88	1.36
Mean	**4.56**	**3.23**

Note: We estimate the reference PPG device is accurate to 2 bpm

System power consumption

Connected mode:



Quiescent: 11.3 µA

System power consumption

If measure heart rate for 30 s every hour this gives an average current draw of 86 μW

Gives 48 days battery life from a miniature 100 mAh battery

Step change for a wrist worn ECG IoT device weighing only 29 g

Future steps

- ✓ Improve signal quality further
- ✓ Use electrodes to provide touch input to the wearable
- ✓ Add 3 electrode design
- ✓ Use capacitive driven right leg

Summary

30 g ultra low power ECG unit

Integrates with UK IoT smart home demonstrator

Battery life >1 month

Personalisable electrodes

christopher.beach@manchester.ac.uk

www.eee.manchester.ac.uk/sisp