Thermal Imaging-based Physiological and Affective Computing

Dr. Youngjun Cho
Assistant Professor
Department of Computer Science
University College London

youngjun.cho@ucl.ac.uk

Key reference

Physiological and Affective Computing through Thermal Imaging: A Survey

YOUNGJUN CHO, Department of Computer Science, University College London (UCL), United Kingdom
NADIA BIANCHI-BERTHOUZE, Division of Psychology and Language Sciences, University College London (UCL), United Kingdom

ABSTRACT

Thermal imaging-based physiological and affective computing is an emerging research area enabling technologies to monitor our bodily functions and understand psychological and affective needs in a contactless manner. However, up to recently, research has been mainly carried out in very controlled lab settings. As small size and even low-cost versions of thermal video cameras have started to appear on the market, mobile thermal imaging is opening its door to ubiquitous and real-world applications. Here we review the literature on the use of thermal imaging to track changes in physiological cues relevant to affective computing and the technological requirements set so far. In doing so, we aim to establish computational and methodological pipelines from thermal images of the human skin to affective states and outline the research opportunities and challenges to be tackled to make ubiquitous real-life thermal imaging-based affect monitoring a possibility.

KEYWORDS

Thermal imaging, physiological computing, affective computing, human temperature, thermography

Cho and Berthouze (2019)
arXiv:1908.10307

What do we learn today?

The emerging field of

Thermal **I**maging-based **P**hysiological and **A**ffective computing (**TIPA**)

Part I　　　(14:00 – 15:00)	Introduction to TIPA & Thermal Imaging Demo

Coffee break

Part II & III (15:30 – 17:30)	Computational Pipeline & Practical guide with TIPA opensource toolkit
	Challenges and research opportunities

What do we learn today?

Part I (14:00 – 15:00) Introduction to TIPA & Thermal Imaging Demo

ACII 2019 Tutorial

Part I: Introduction to Thermal Imaging-based Physiological and Affective Computing

Dr. Youngjun Cho
Assistant Professor

youngjun.cho@ucl.ac.uk

What do we learn during Part I?

We will introduce

    1) Thermal Imaging and its typical applications

    2) Temperature responses to our affective states

    3) Types of physiological signatures which can be measured
       through thermal imaging

Introduction to Thermal Imaging and Applications

Earlier temperature measurements
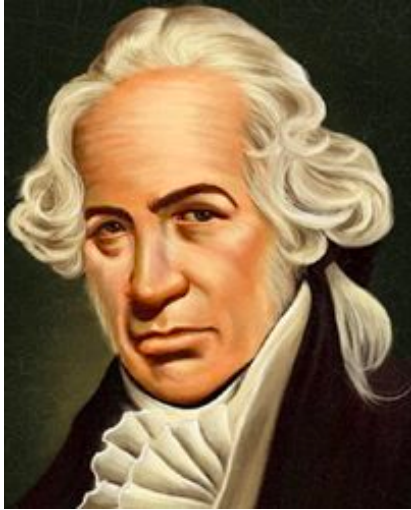
The first mercury thermometer
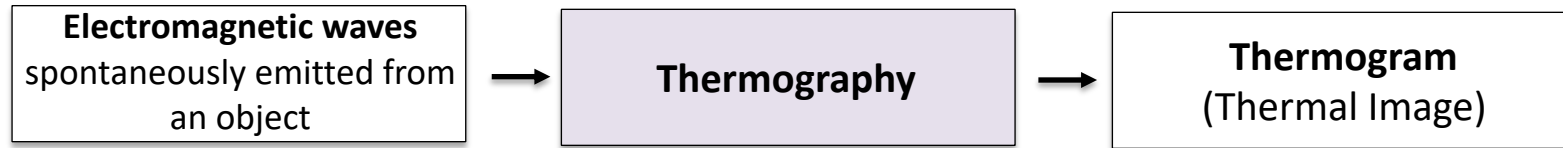invented by **Daniel Gabriel Fahrenheit** (1714)
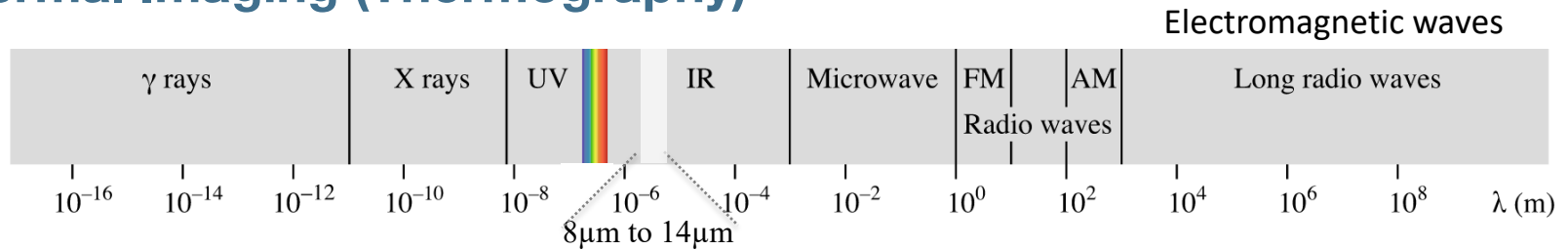
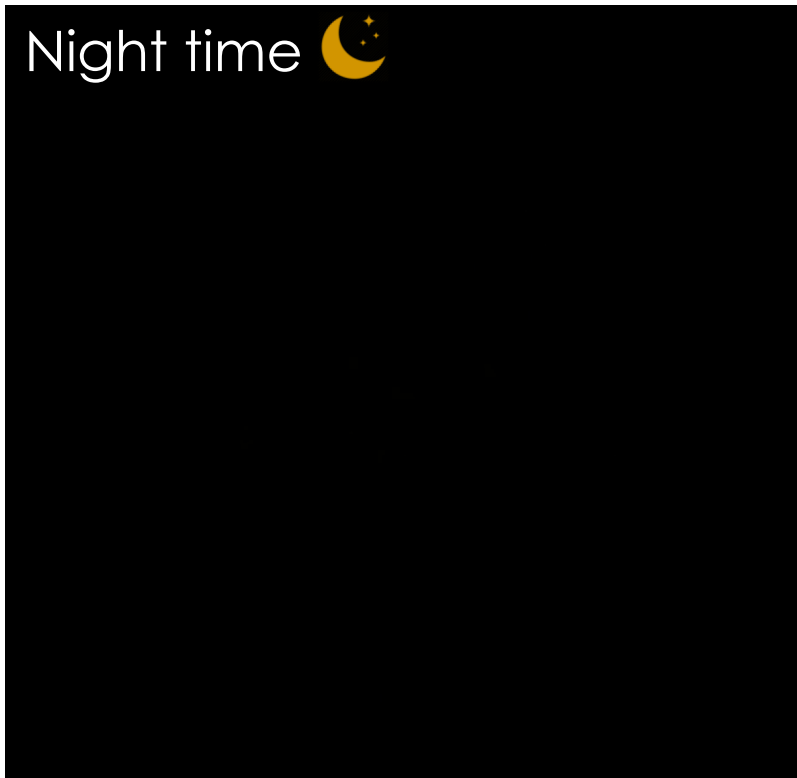**Surface thermometer (1877)**
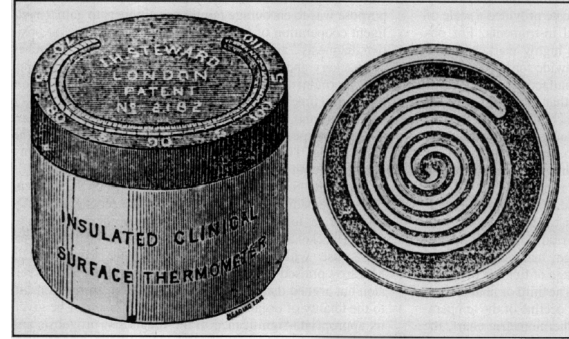
Curved thermometer (circa 1903)
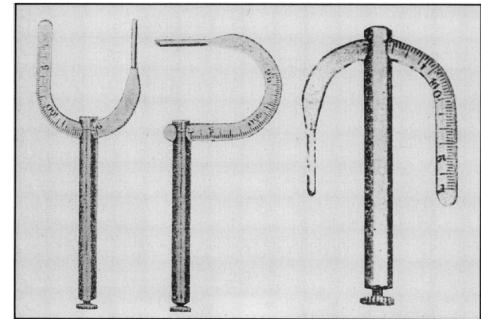
Contact-less temperature measurement

Thermal Imaging (Thermography)

Electromagnetic waves

	γ rays	X rays	UV		IR	Microwave	FM	AM	Long radio waves

Radio waves

10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} λ (m)

8μm to 14μm

Electromagnetic waves spontaneously emitted from an object	→	**Thermography**	→	**Thermogram** (Thermal Image)

◆FLIR

RGB Camera

Thermal Camera

Night time 🌙✨

Night time 🌙✨
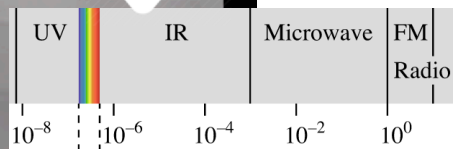
Cho et al. (2018)

Fundamental advantages

Contact-free

No need of light sources

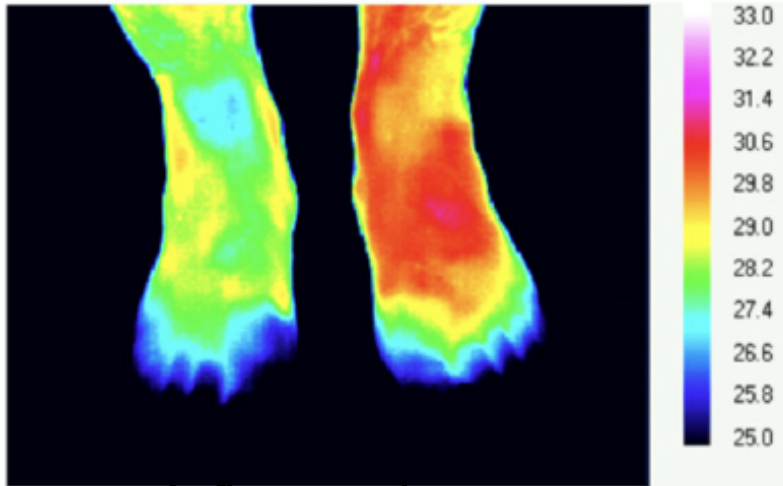Less privacy concerns

Cho et al. (2017)
Biomedical Optics Express

Medical Applications of Thermal Imaging

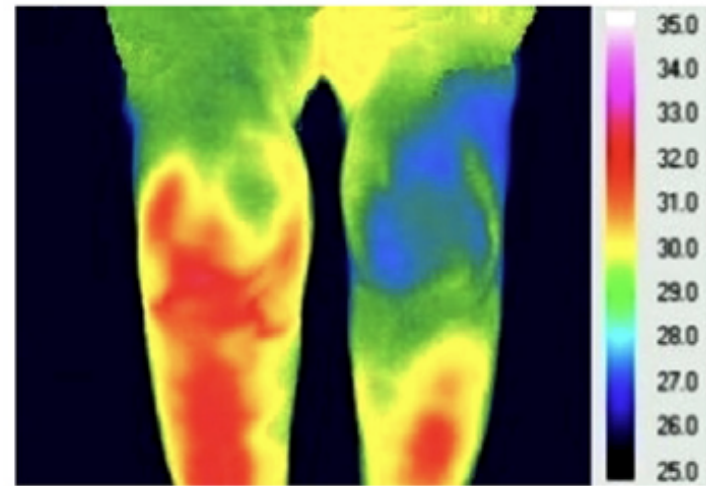Diagnostic tools for tumors, Rheumatism, Complex Regional Pain Syndrome etc.

CHCH YOUR HEALTH

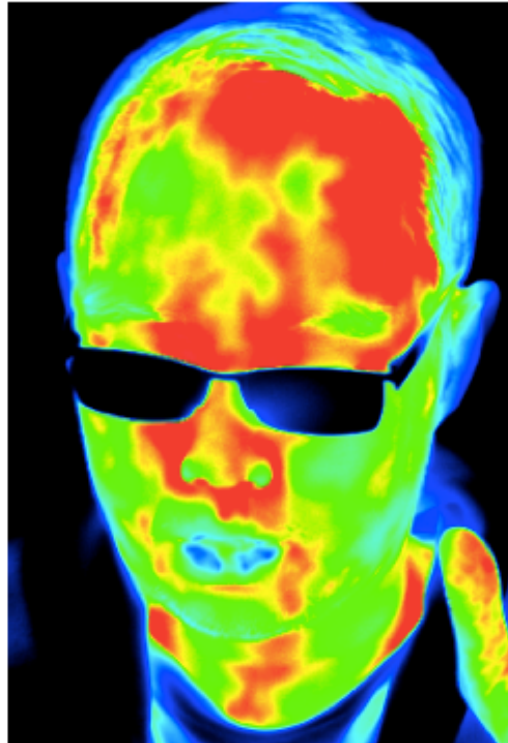# Medical Applications of Thermal Imaging

Diagnostic tools for tumors, Rheumatism, etc.
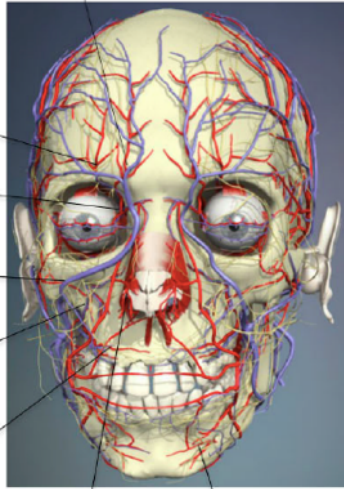

Inflammation
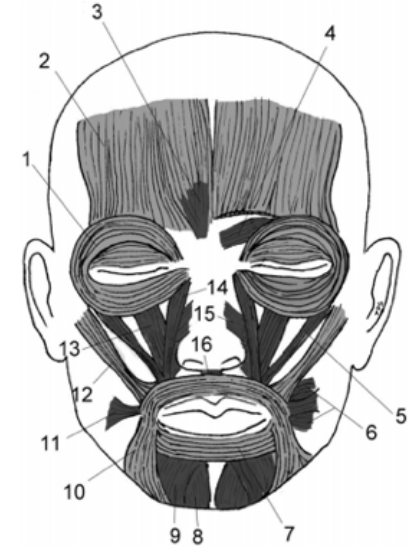following a sports injury

Rheumatoid arthritis

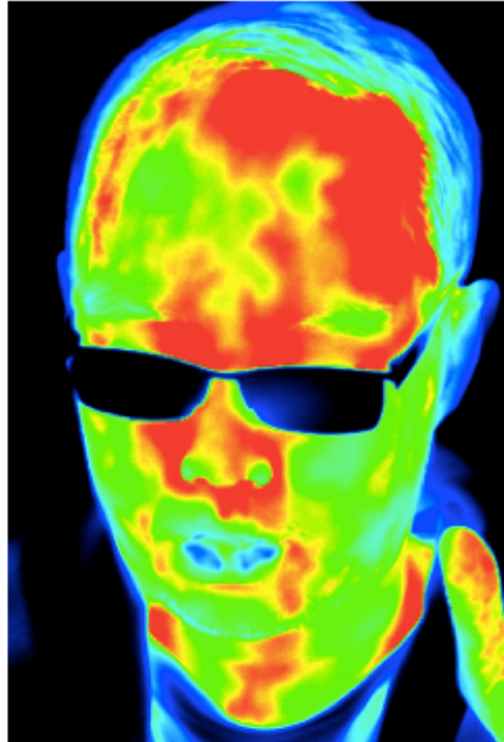Ring and Ammer (2012)

Thermal Imaging for Affective Computing

Facial Anatomy and Temperature Distribution
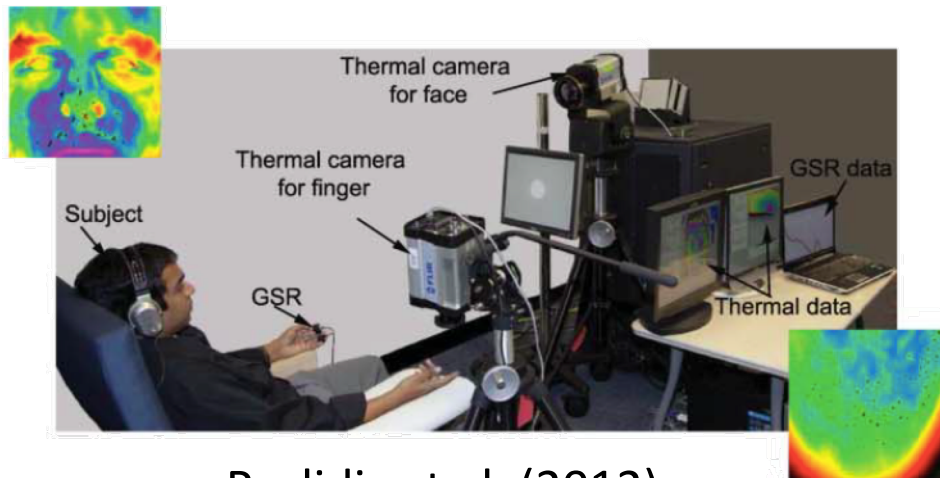
Facial Anatomy and Temperature Distribution

Blood artery network

Muscles contraction

Waller et al. (2008)   Palermo et al. (2013)   Ioannou et al. (2014)

Typical setups for thermal imaging-based affective computing
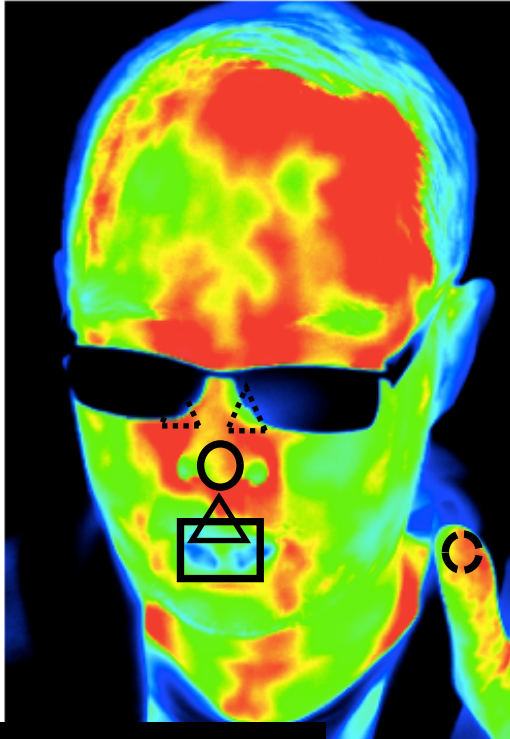

Pavlidis et al. (2012)

Jarlier et al. (2011)

Temperature Directional Change along with Affective States

Cho et al. (2019)

Mental Stress, Mental workload

○ Nose tip ⬇ Genno et al. (1997), Or and Duffy (2007), Veltman et al. (2005), Engert et al. (2014), Cho et al. (2019)

Fear

◌ Finger tip ⬇ Kistler et al. (1998)

Startled

△ Upper lip ⬇ ⬠ Periorbital ⬆ Shastri et al. (2012)
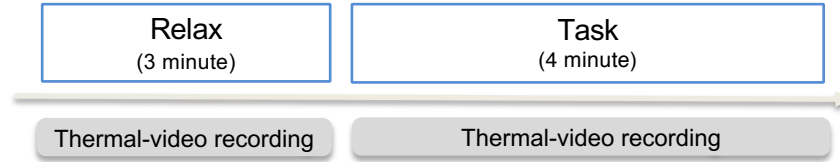
Pavlidis et al. (2001)

Sexual Arousal
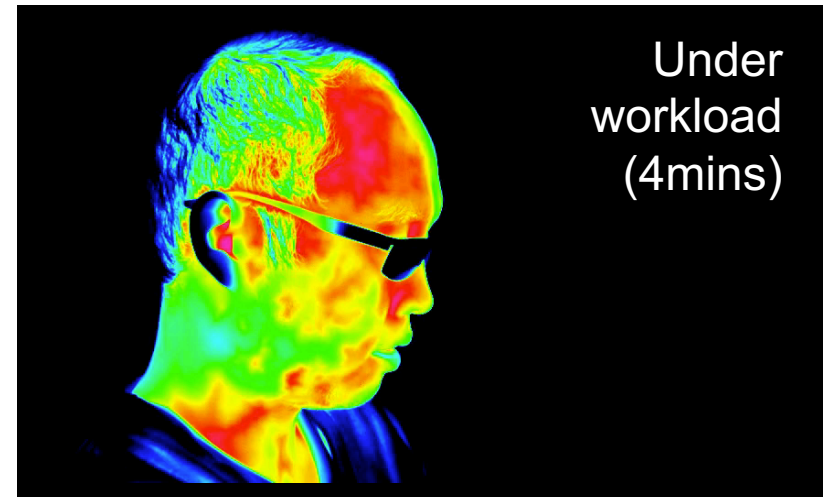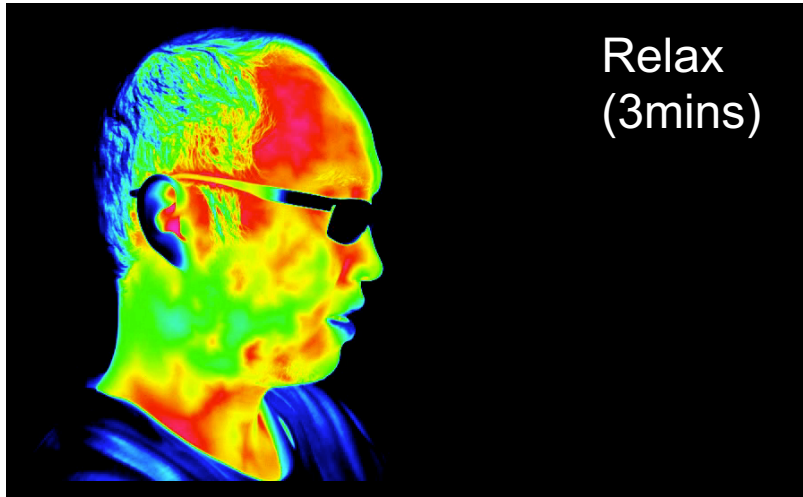
▭ Mouth ○ Nose tip ⬠ Periorbital ⬆ Hahn et al. (2012)

Love

Whole face ⬆ Salazar-López et al. (2015)

Example: changes in the nose tip temperature under mental workload

Relax (3 minute)   Task (4 minute)

Thermal-video recording   Thermal-video recording

Task: **Game**

adamatomic.com/**canabalt**/

Relax (3mins)

Under workload (4mins)

Example: changes in the nose tip temperature under cognitive load
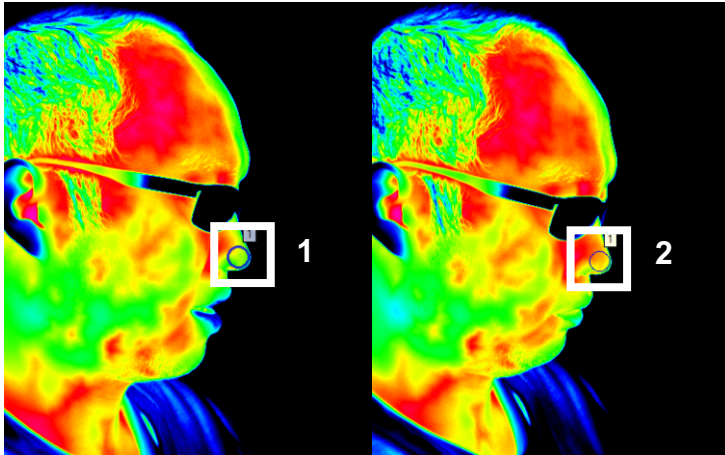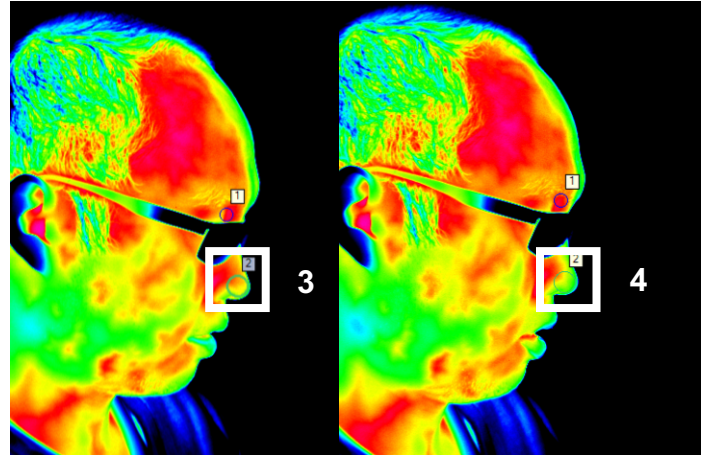
Key limitation: Static thermal imaging

Pereira et al. (2015)

Thermal camera for face

Thermal camera for finger

Subject

GSR

GSR data

Thermal data
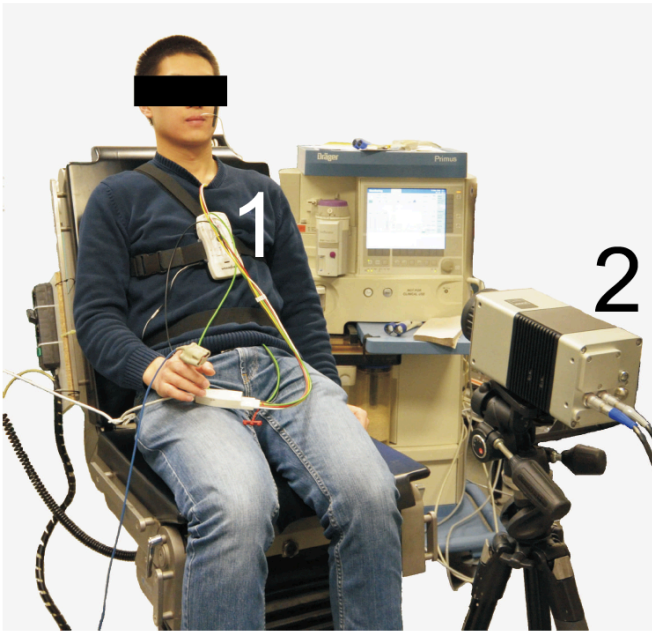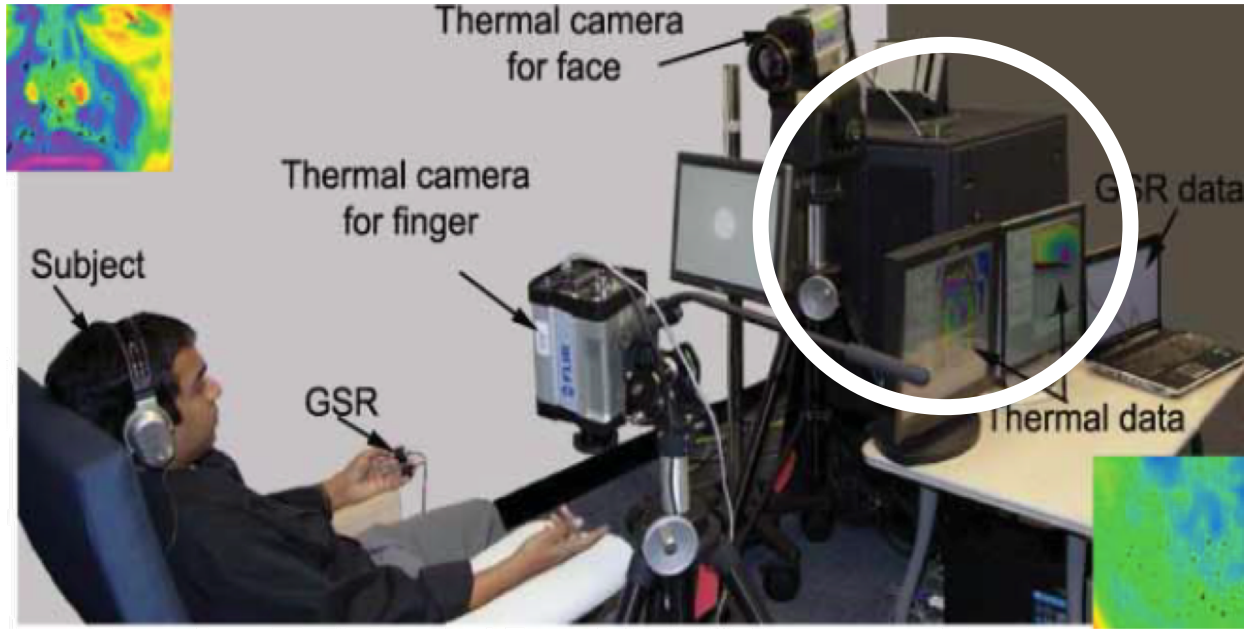
Pavlidis et al. (2012)

Advanced technology has emerged:
Mobile, Low-cost Thermal Imaging device

Expensive static system   Low-cost mobile system

Advanced technology has emerged:
Mobile, Low-cost Thermal Imaging device

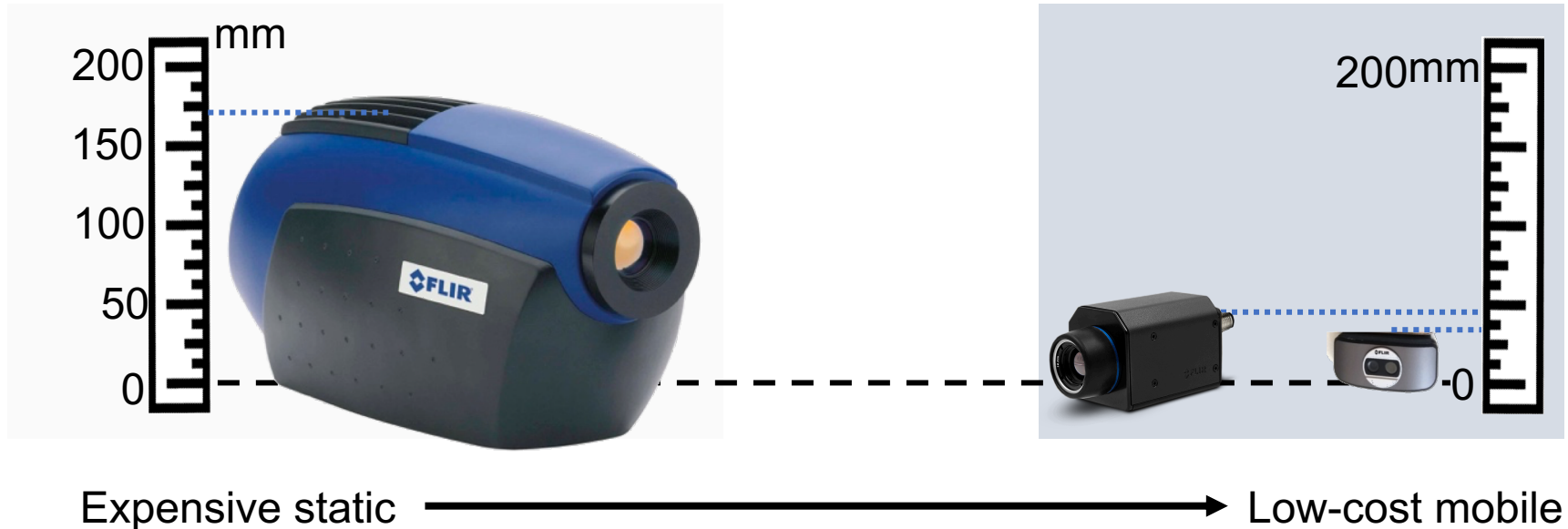Expensive static ⟶ Low-cost mobile

Cho et al. (2019)

Advanced technology has emerged:
Mobile, Low-cost Thermal Imaging device
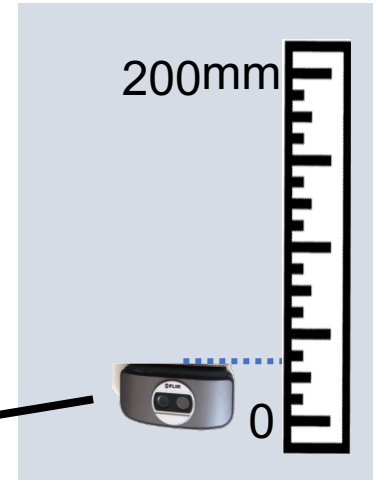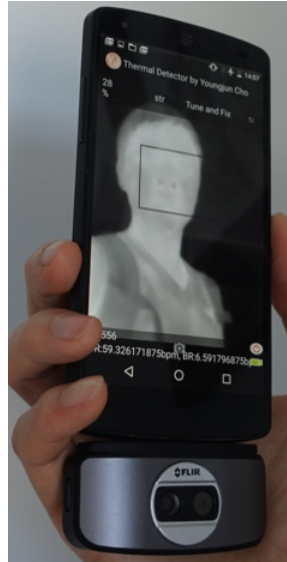

Expensive static

Cho et al. (2019)

Mobile thermal imaging possible

Integrated into a smartphone

200mm

0

Low-cost mobile

Specification, size and price of systems

Product	Spatial Resolution	Sampling Rate	Thermal Sensitivity (NETD)	Device Dimension	Weight	Price[±] (in August 2019)
[+]FLIR One 3G	80x60	<8.7Hz (unsteady)	0.10°C**	68 x 34 x 14 mm^3	34.5g	$199.99
[+]FLIR One 2G	160x120	<8.7Hz (unsteady)	<0.10°C	68 x 34 x 14 mm^3	36.5g	Not available (in Aug 2019) £166.00 (about $239 in May 2016)
[+]Seek Thermal Compact	206x156	<9Hz (unsteady)	0.50°C	25.4 x 45 x 20 mm^3	14g	$249.00

. . .

Product	Spatial Resolution	Sampling Rate	Thermal Sensitivity	Device Dimension	Weight	Price
*FLIR A655sc	640x480	50Hz	<0.03°C	216 x 73 x 75 mm^3 (Without lens)	900g	$24,662.43
*FLIR SC5000mb	640x512	100Hz	0.017°C	320x141x159 mm^3	3800g	Unknown
*FLIR SC7650	640x512	100Hz	0.020°C	253x130x168 mm^3 (Without lens)	4950g (Without lens)	Unknown

Cho et al. (2019) https://arxiv.org/abs/1908.10307

Thermal Imaging for Physiological Computing

Physiological Computing

To enable technology that listens to our bodily functions and psychological needs

Cho et al. (2019)
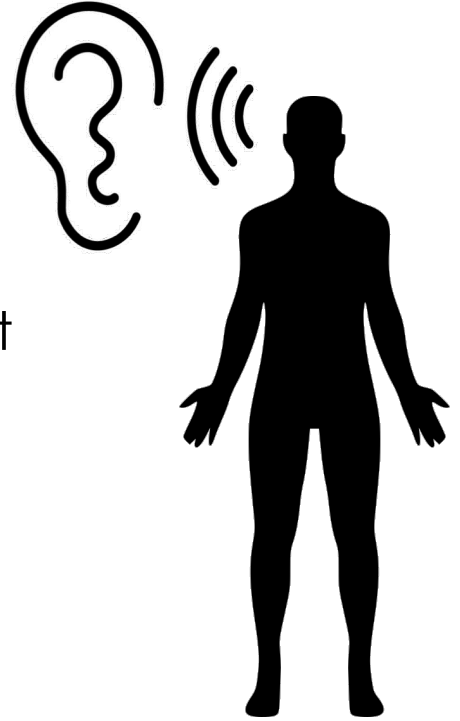
Physiology?

Definition:
The branch of biology that deals with the normal functions of living organisms and their parts.

The way in which a living organism or bodily part functions.

Autonomic nervous system (ANS)

The part of the nervous system responsible for
control of the bodily functions not consciously directed,
such as
breathing, the heartbeat, perspiration, sexual arousal and digestive
processes.

- Parasympathetic nervous system
- Sympathetic nervous system
- (Enteric nervous system)

Parasympathetic division

Sympathetic division
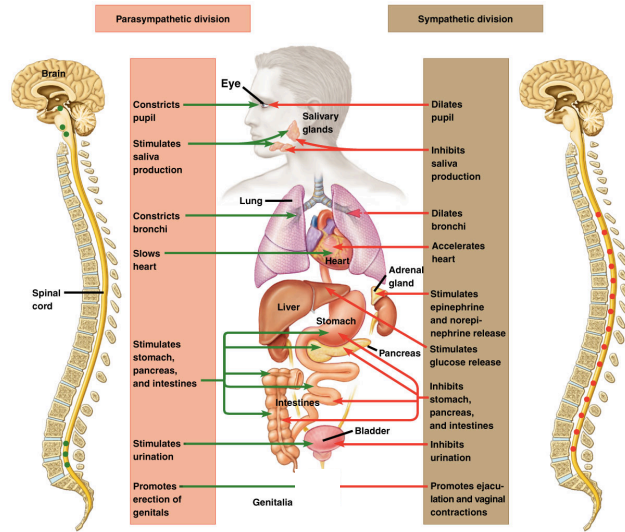
Parasympathetic system

- Heartbeat slows
- Blood pressure reduces
- Respiration levels
- Your body experiences visceral responses typical of periods of rest and relaxation.
- Rest and digest
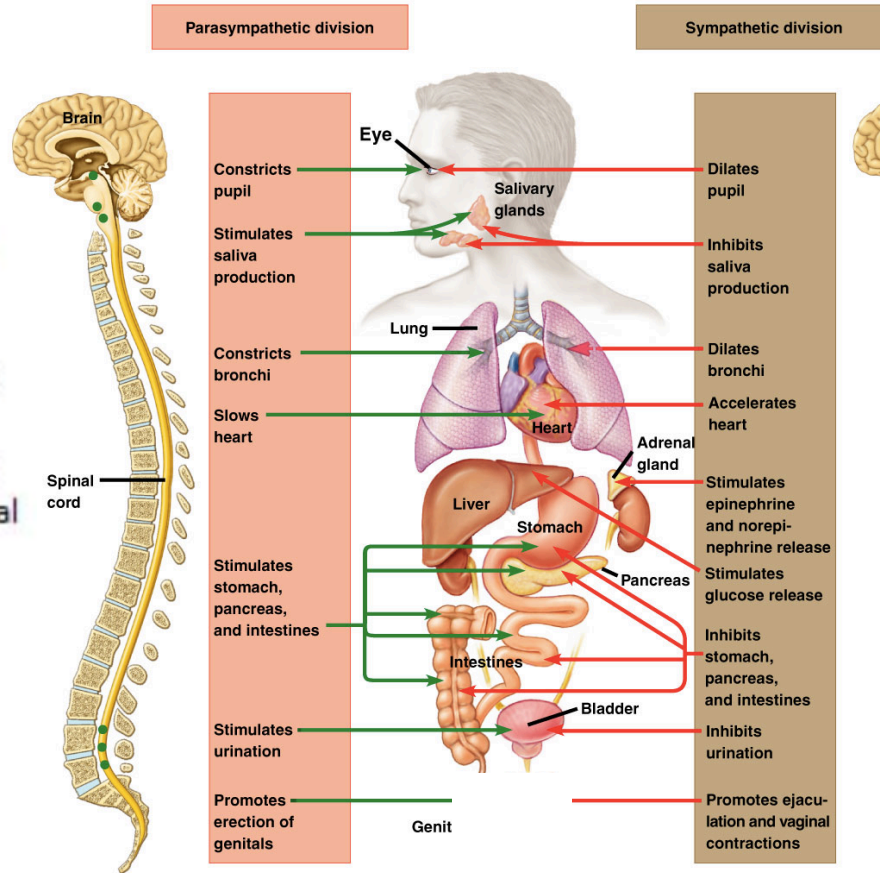
Sympathetic system

- Heart and blood pressure increases
- Respiration accelerates, blood sugar is released from the liver
- Adrenalin, noradrenalin are released from the adrenal glands.
- Fight or flight

Brain

Eye

Constricts pupil

Stimulates saliva production

Salivary glands

Dilates pupil

Inhibits saliva production

Lung

Constricts bronchi

Slows heart

Heart

Dilates bronchi

Accelerates heart

Adrenal gland

Spinal cord

Liver

Stomach

Stimulates epinephrine and norepi-nephrine release

Stimulates stomach, pancreas, and intestines

Pancreas

Stimulates glucose release

Intestines

Inhibits stomach, pancreas, and intestines

Stimulates urination

Bladder

Inhibits urination

Promotes erection of genitals

Genit

Promotes ejacu-lation and vaginal contractions

They respond to

Parasympathetic division — Sympathetic division

Brain
Constricts pupil
Eye
Salivary glands
Stimulates saliva production
Lung
Constricts bronchi
Slows heart
Heart
Spinal cord
Liver
Stomach
Stimulates stomach, pancreas, and intestines
Pancreas
Intestines
Bladder
Stimulates urination
Promotes erection of genitals
Genitalia

Dilates pupil
Inhibits saliva production
Dilates bronchi
Accelerates heart
Adrenal gland
Stimulates epinephrine and norepinephrine release
Stimulates glucose release
Inhibits stomach, pancreas, and intestines
Inhibits urination
Promotes ejaculation and vaginal contractions

Physical Activities
(e.g. exercise)

Psychological Activities
(e.g. Mental workload)

How to measure physiological signatures?

Heartbeat?

Muscular activity?

Breathing (Respiration)?

Sweat (Perspiration)?

Cortical activity?

Simple, non-invasive techniques include:

Heart Activity
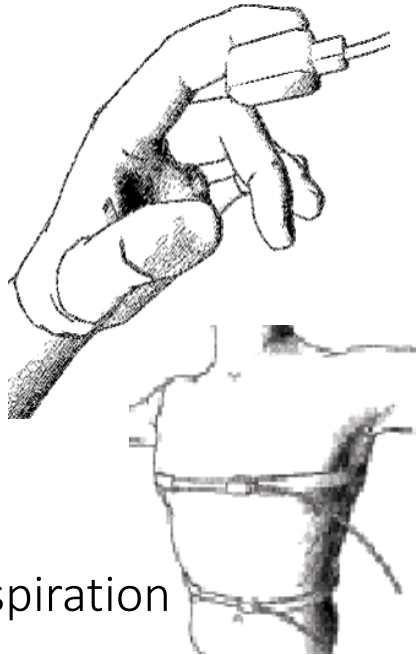
EMG
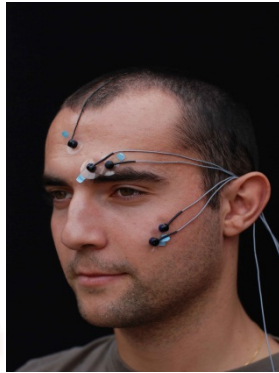
EEG

Peripheral Temperature

Galvanic Skin response (GSR)

Respiration

Physiological measures: Fundamentals

- **Register changes in biological systems**

- **Changes may be so subtle that cannot be identified at behavioural level**

- **Advantages:**
- Hard to control deliberately
- Processed Continuously
- Easily integrated with other measures (self-report and behaviour)

Cardiac pulse (Cardiovascular signature)

Typical signal forms

ECG
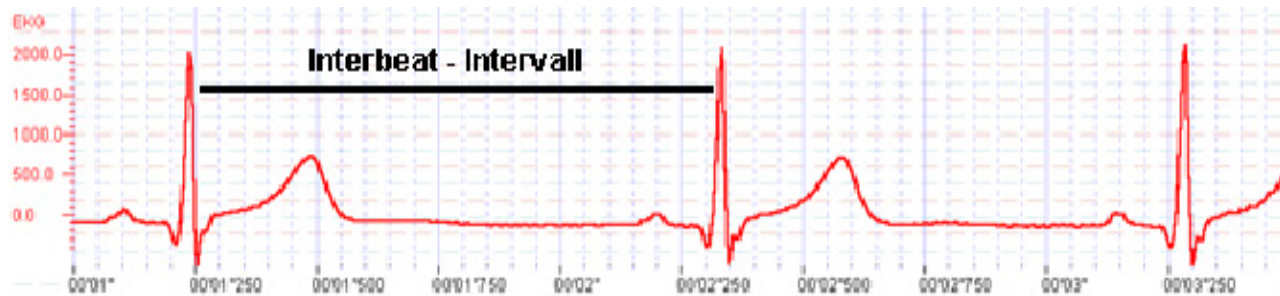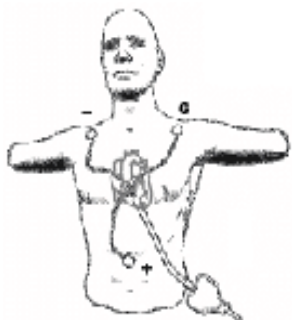
PPG
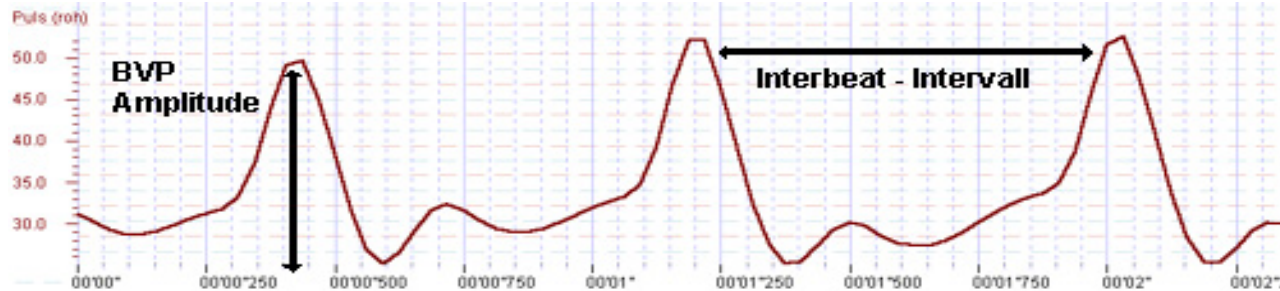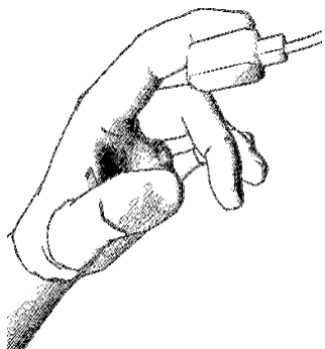
ECG and PPG

1 **Cardiac pulse (Cardiovascular signature)**

- Heart rate (HR): number of beats per unit of time (beats per minute - bpm)
- Interbeat interval (IBI): time (ms) between two R wave peaks
- Heart Rate Variability (HRV) features (e.g. SDPP etc.)
- Resting: HR~72 bpm; IBI~830 ms

- Typical cues:
  - Decrease in HR: relaxation
  - Decreasing IBI, Increasing HR: stress, frustration, anger
  - Increase of attention causes short term HR deceleration. Arousal causes long term HR acceleration.
- Affected by environmental changes, physical activity, drugs (coffee, nicotine), age, gender; fitness; etc.
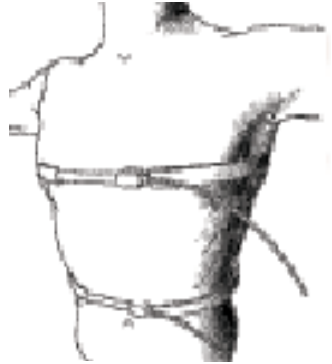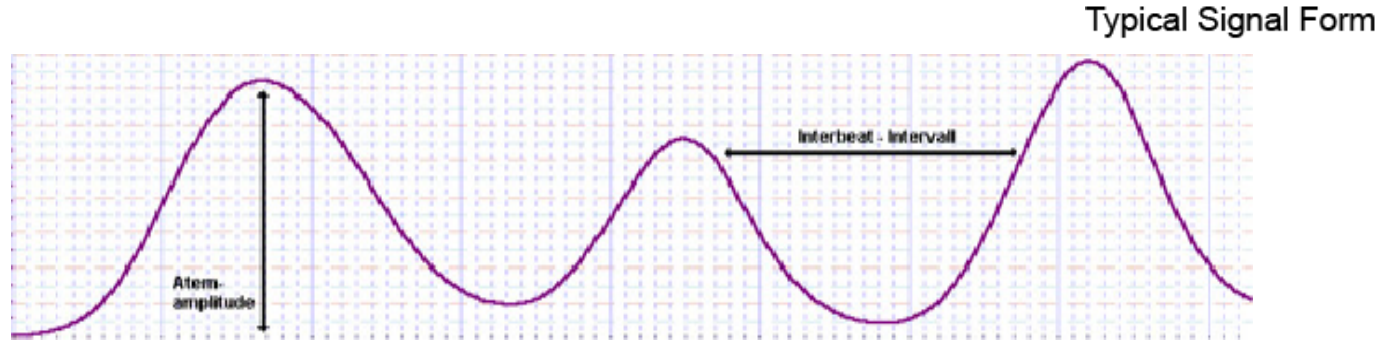
2 **Breathing (Respiratory signature)**

Position

Typical Signal Form

Atem-amplitude

Interbeat - Intervall

Breathing (Respiratory signature)

Typical Signal Form

Atem-amplitude

Interbeat - Intervall
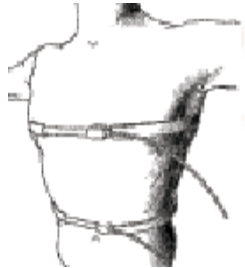
Position

- **Relative measure of chest expansion**
- **On the chest or abdomen**
- **Respiratory rate (RR) and relative respiration amplitude (RA)**
- **Typical cues:**
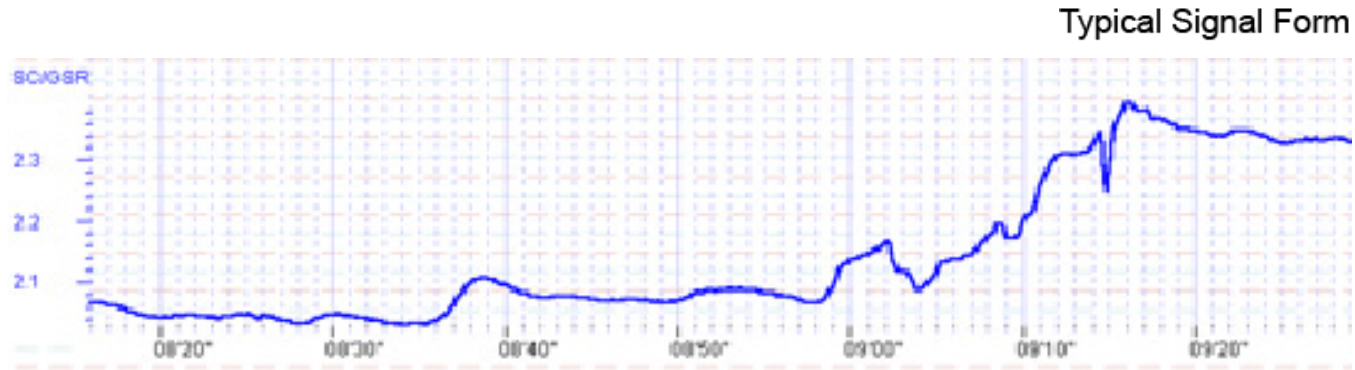   - Increasing RR – anger, joy, exercise
    - Decreasing RR – relaxation, bliss

Galvanic Skin Response (Perspiratory signature)

Also called Skin Conductivity (SC) or Electrodermal Activity (EDA)

Empatica

Typical Signal Form

Galvanic Skin Response (Perspiratory signature)
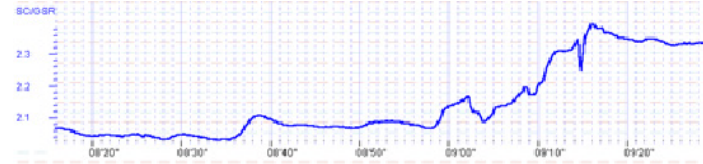
- **Tonic SC:** **baseline level of skin conductance (SCL) in absence of any stimuli**

    Different people have different levels (range 10-50 µS: micro-Siemens)

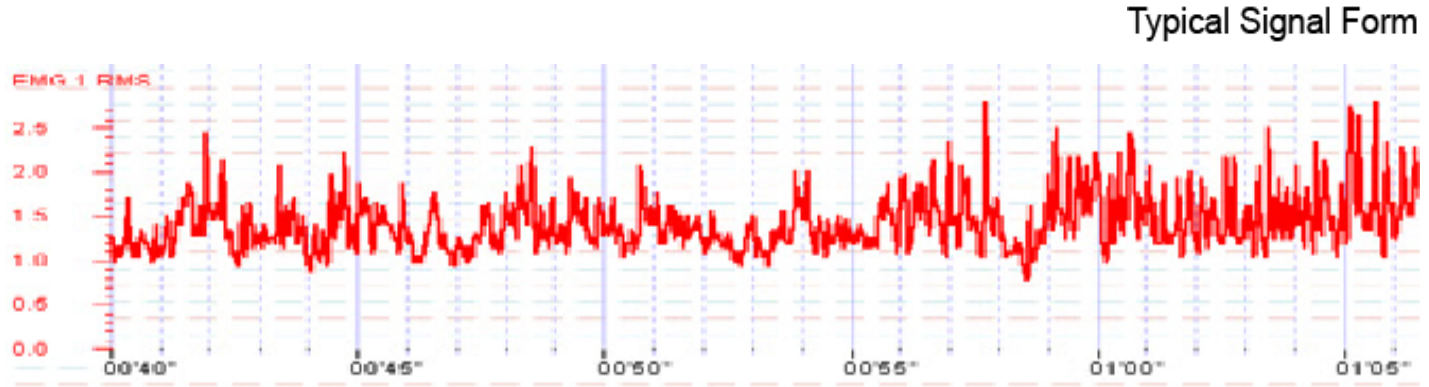   Vary all the time according to psychological state and autonomic regulation

- **Phasic SC:** **Changes in response to an event.**

    Can last 10-20 sec. before going back to baseline
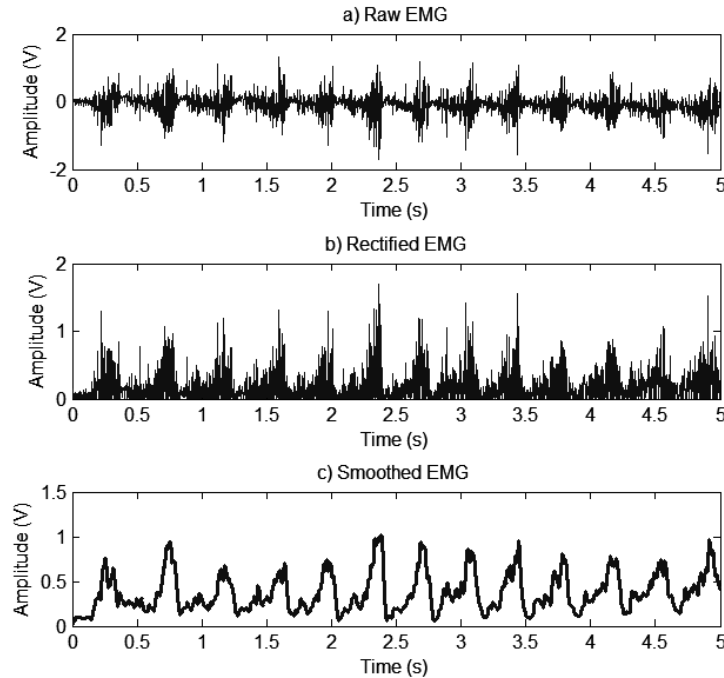
- SCR Amplitude, SCR Latency, SCR Rise time, Half-recovery time
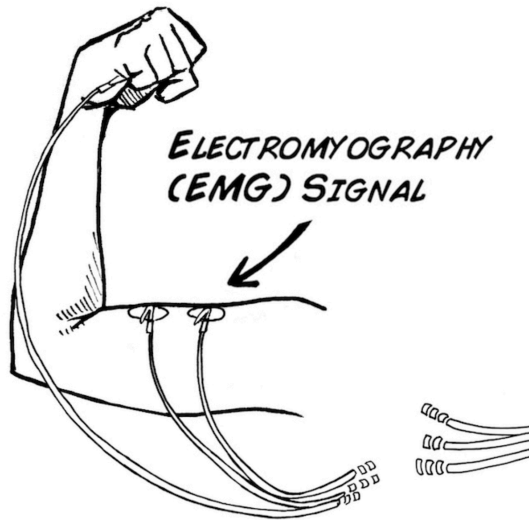
Muscular signature

Body Electromyography (EMG)

Typical Signal Form

Myo

Muscular signature

Body Electromyography (EMG)

ELECTROMYOGRAPHY (EMG) SIGNAL

a) Raw EMG

b) Rectified EMG

c) Smoothed EMG

Typical
EMG preprocessing

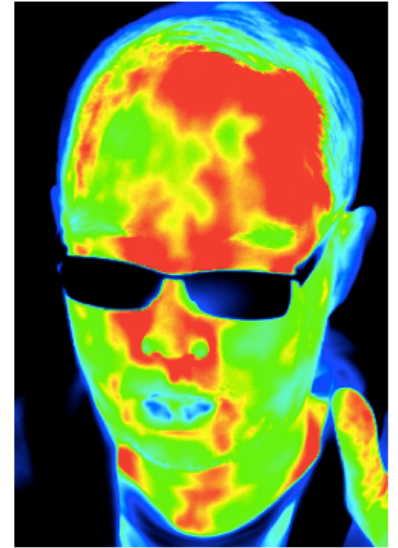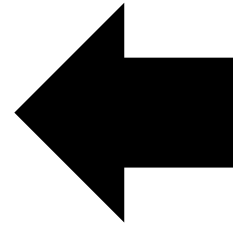1) Rectification

2) Smoothing

Physiological Thermal Signatures

1 **Cardiovascular signature**

2 **Respiratory signature**

3 **Perspiratory signature**

4 **Muscular signature**

Physiological Thermal Signatures

1 **Cardiovascular signature**

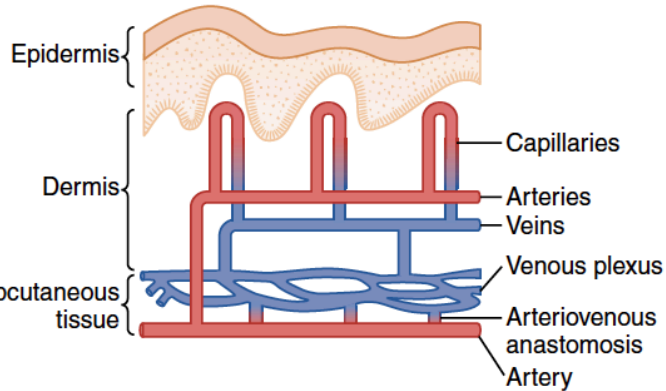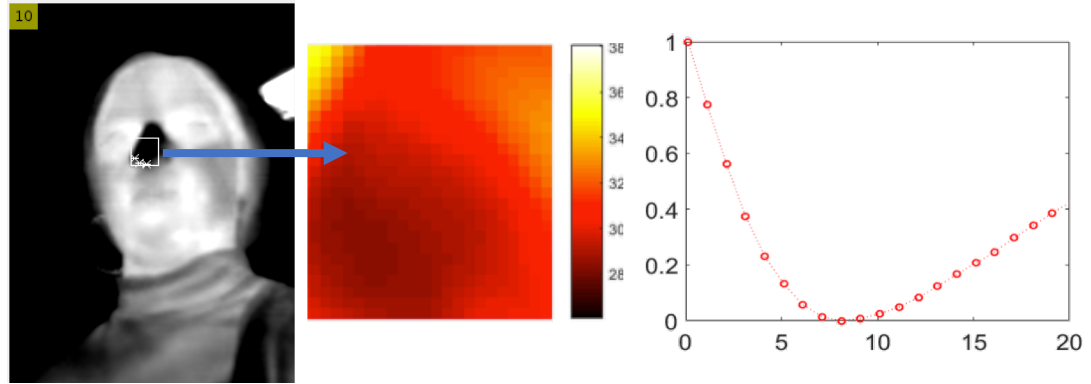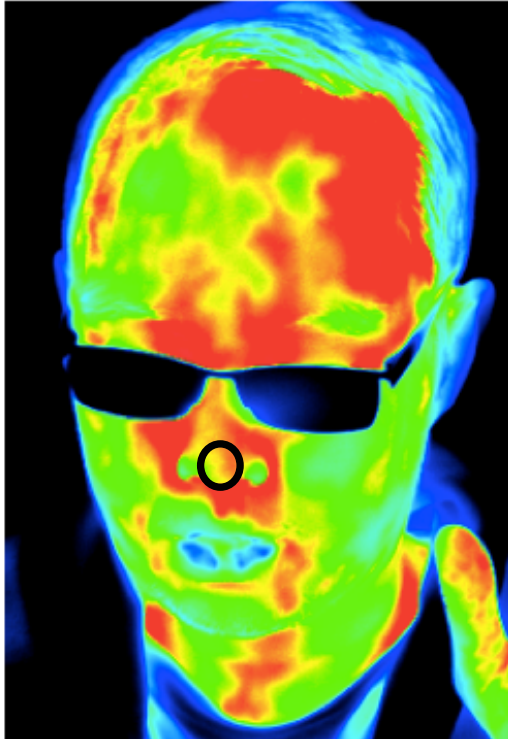Vasoconstriction-induced changes (vasomotor)

Figure 73-2 Skin circulation.

Hall and Guyton (2011)

Instant Stress (JMIR Mental Health, Cho et al. 2019)

Remind you

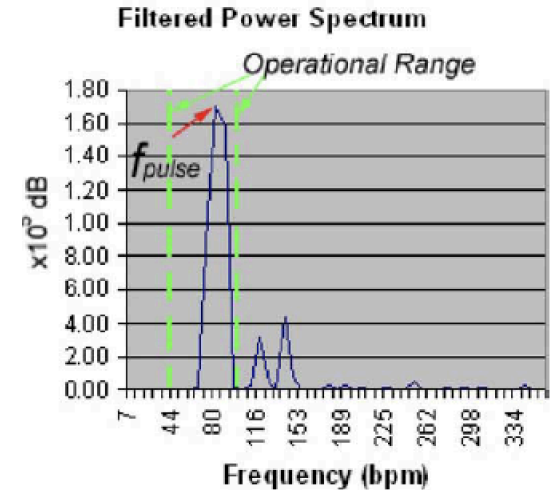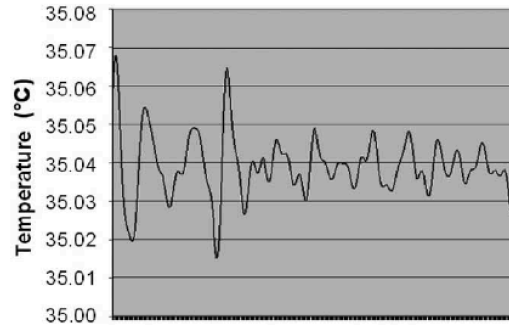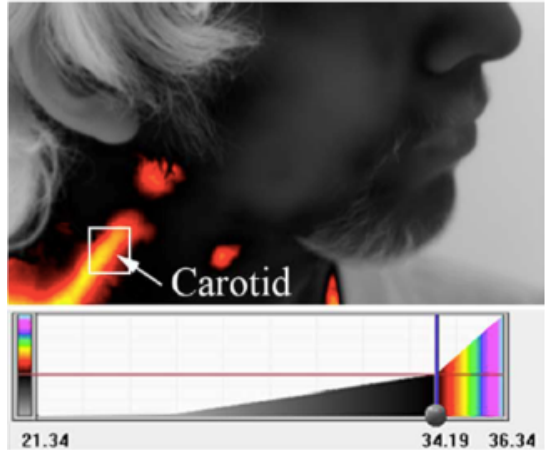## Mental Stress, Mental workload

O Nose tip

Genno et al. (1997), Or and Duffy (2007), Veltman et al. (2005), Engert et al. (2014), Cho et al. (2019)

Cho et al. (2019)

Physiological Thermal Signatures

1 **Cardiovascular signature**
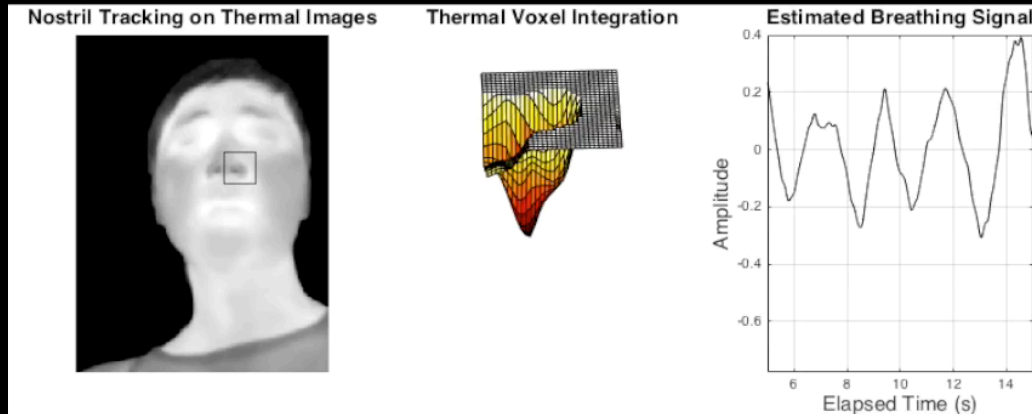
Cardiac Pulse rate (*low reliability)

Garbey et al. (2007)

Physiological Thermal Signatures

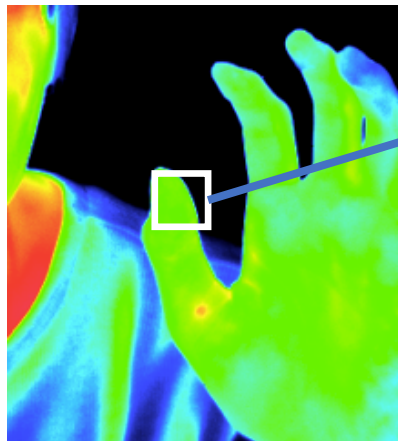**2** **Respiratory signature**

Breathing signals (*very accurate)

Cho et al. (2017)
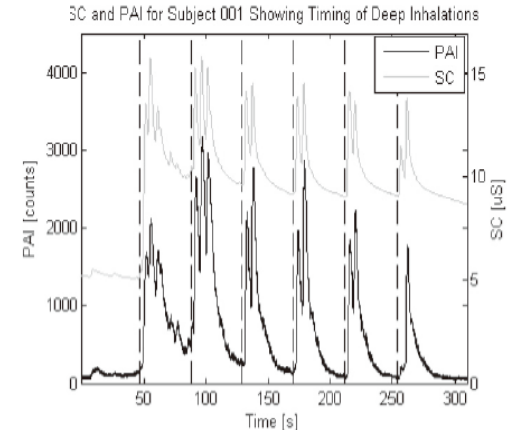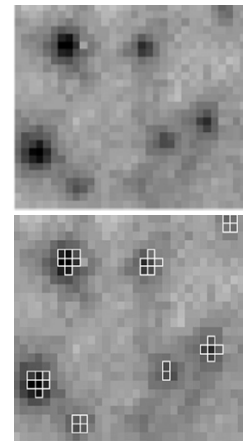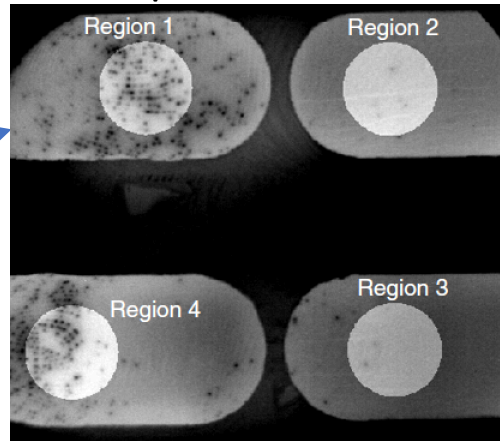Biomedical Optics Express

Physiological Thermal Signatures

3 **Perspiratory signature**

Sweat gland activation

Active pores

Krzywicki et al. (2014)

Physiological Thermal Signatures

4 **Muscular signature**

Facial micro-muscle activation

Facial Action Coding System (FACS) ?

FACS categorizes the physical "micro facial muscle (Action Unit)" expression of emotions

e.g. Emotion and Action Unit (right)
   - P. Ekman and W. V. Friesen (1978)

Emotion	Action Unit
Happiness	6+12
Sadness	1+4+15
Surprise	1+2+5B+26
Fear	1+2+4+5+20+26
Anger	4+5+7+23
Disgust	9+15+16

Physiological Thermal Signatures

4 **Muscular signature**

Facial micro-muscle activation
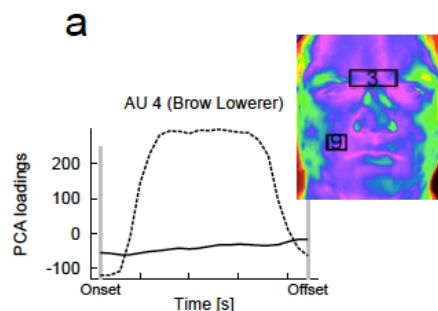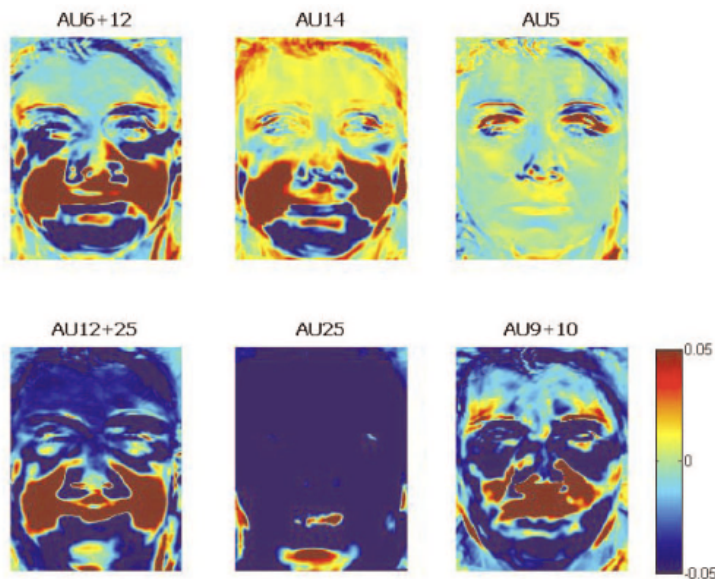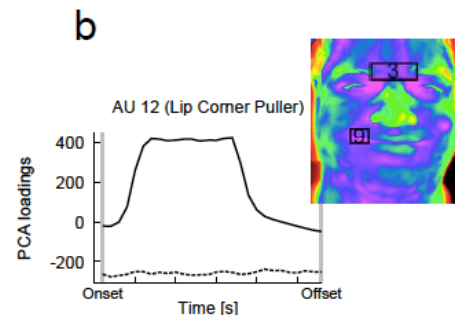
Angry   Happy

Jarlier et al. (2011)

Physiological Thermal Signatures
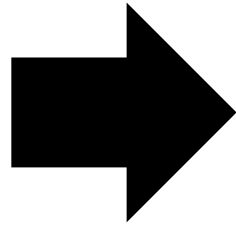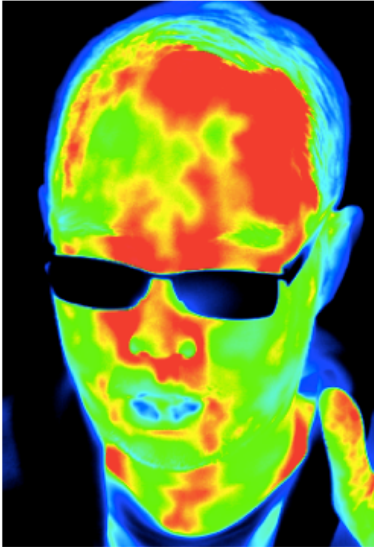
1 **Cardiovascular signature**

2 **Respiratory signature**

3 **Perspiratory signature**

4 **Muscular signature**

Cho (2019)

Cho (2019)
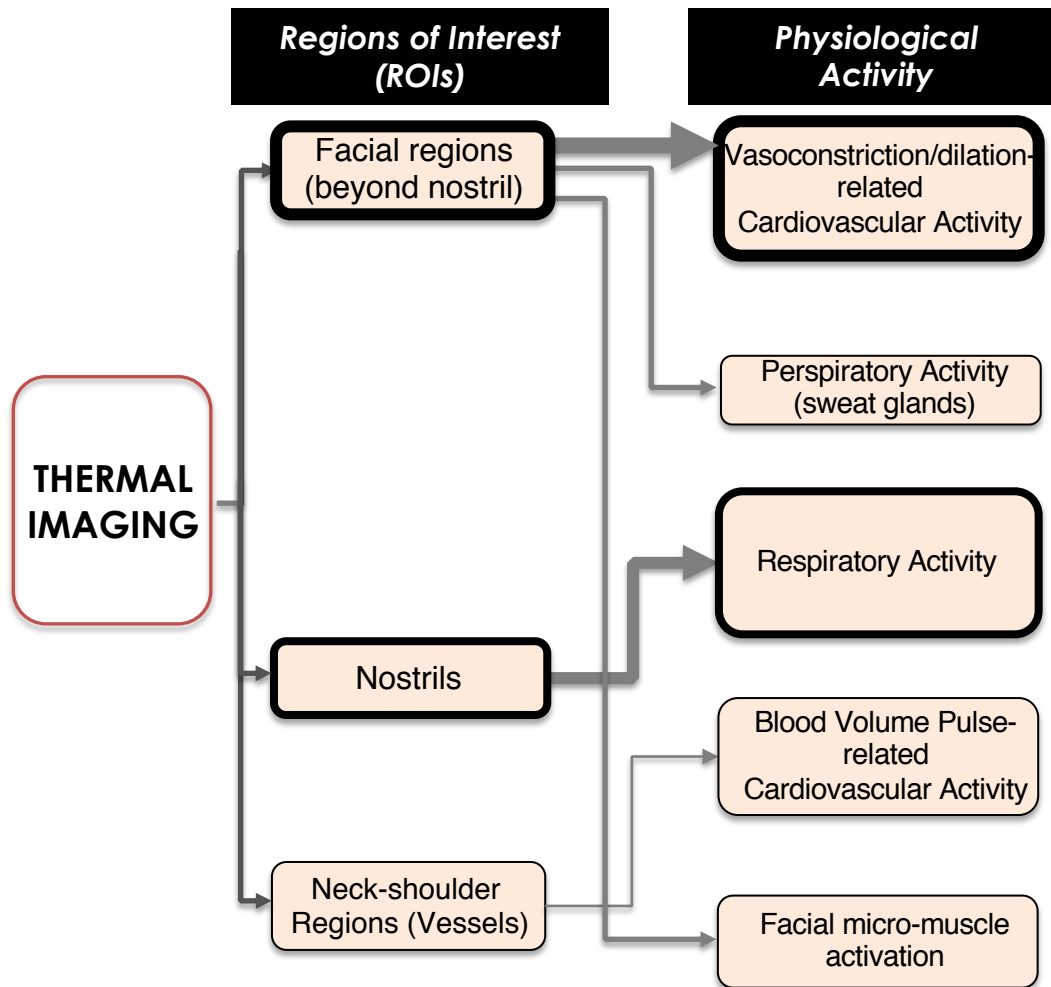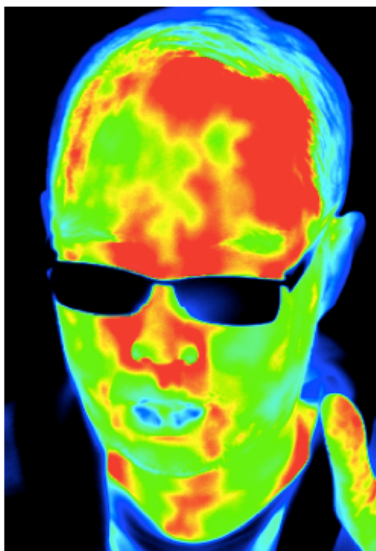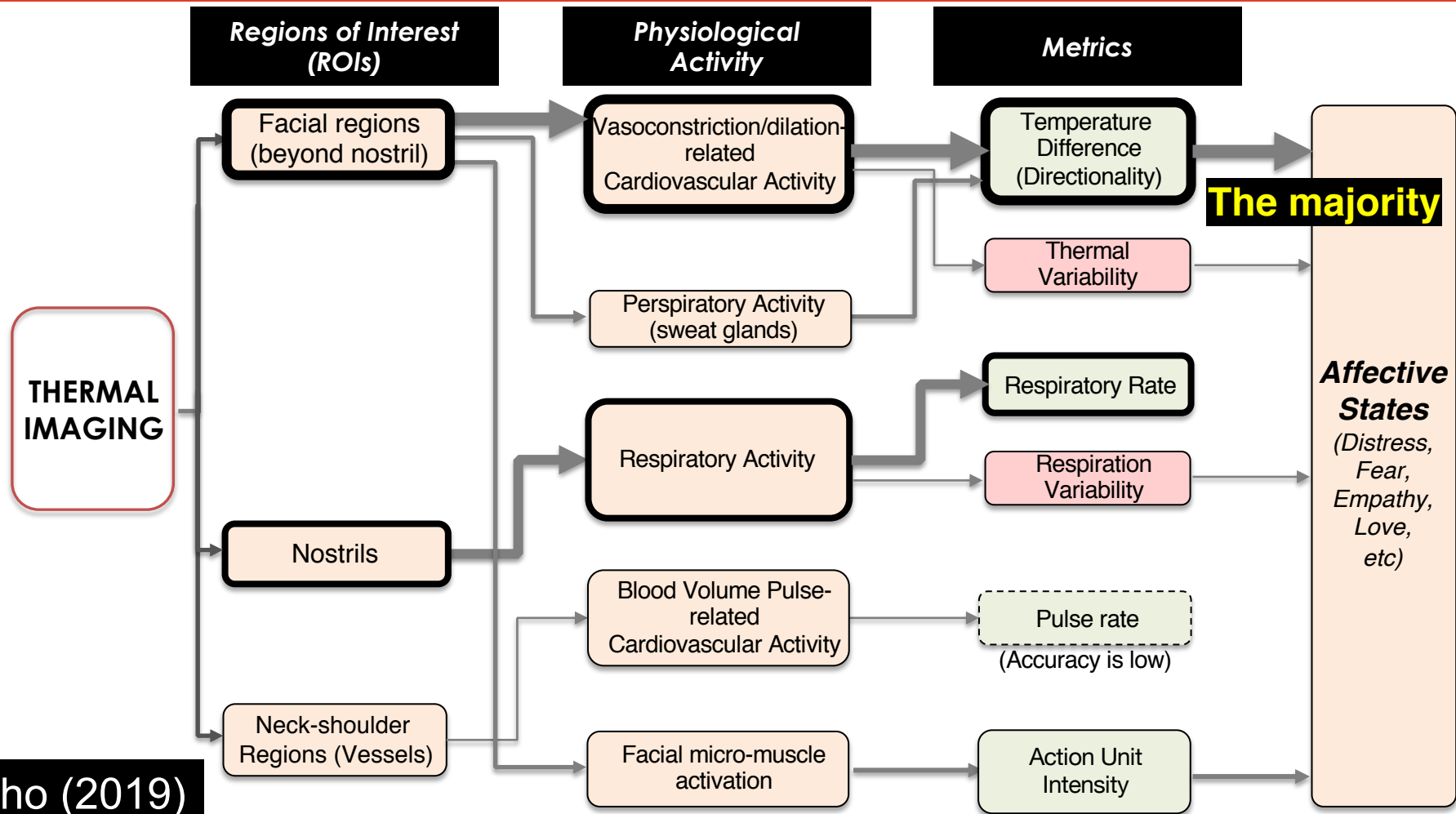
Coffee Break (15:00 – 15:30)

Part II & III (15:30 – 17:30)

Computational Pipeline & Practical guide
with TIPA opensource toolkit

Challenges and research opportunities

Any questions?

& thermal imaging demo

Dr. Youngjun Cho

Assistant Professor, Department of Computer Science, University College London (UCL)

Home | News | Physiological Computing & AI Lab ⌄ | Datasets | Blog & Archive | Press | Contact

Home › TIPA Opensource project

TIPA Opensource project

Thermal Imaging-based Physiological and Affective computing (TIPA)

TIPA Opensource project

Created: August 2019 (very initial stage)
Author(s): Dr. Youngjun Cho (Assistant Professor, Department of Computer Science, University College London, UCL)

This project is to support the ACII 2019's tutorial on Thermal Imaging-based Physiological and Affective computing

Full source code: https://github.com/deepneuroscience/TIPA
Example dataset: Link
Temporary TIPA opensource project website: http://youngjun.cho/TIPA

Key Reference

[1] Youngjun Cho and Nadia Bianchi-Berthouze. 2019. Physiological and Affective Computing through Thermal Imaging: A Survey. arXiv:1908.10307 [cs], http://arxiv.org/abs/1908.10307

Further Technical References

25 commits   1 branch

Branch: master ⌄   New pull request

deepneuroscience Update README.md

📁 TIPA_library
📁 data
📁 figures
📄 README.md
📄 TIPA_basic_run.ipynb

Brief guideline

1. Download Anaconda (latest version) - Python 3.7 (recommended)

   https://www.anaconda.com/distribution/

2. Install basic libraries on the Conda console.

   conda install -c conda-forge opencv

   conda install scikit-learn

   pip install --upgrade numpy

   pip install --upgrade matplotlib

   conda install -c anaconda scipy

   - For your information

   print(python_version())

   3.7.3

   print(np.version.version)

   1.16.4

   print(cv2.**version**)

   3.4.2

   scipy (1.3.1)

3. Run "TIPA_basic_run.ipynb" on the Jupyter notebook

   You can find a basic instruction on the notebook.

1. Import TIPA libraries

```
In [9]: import sys
        from platform import python_version
        # sys.path.insert(0,'./TIPA_library/')

        from TIPA_library.main.data_preparation import *
        from TIPA_library.main.thermal_image_processing import *
        from TIPA_library.utils import timshow as tim
        from TIPA_library.utils import rvs
```

2. Loading a raw sequence of thermal 2d matrices

The TIPA project mainly uses the TIPA frame protocol below by default.

For FLIR ONE (SDK) users, you can simply implement the code from the link below.
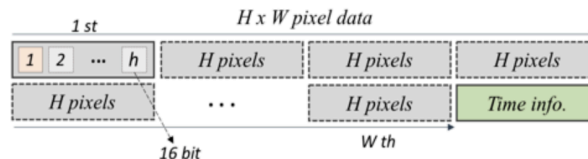https://github.com/deepneuroscience/DeepThermalImaging/tree/master/example%20code%20for%20FLIR%20One%20sdk

Figure 1. TIPA (Thermal Imaging-based Physiological and Affective computing) Project Dataframe protocol

Example Dataset

We provide example data.

Download this dataset - Link
Unzip, move them to a directory (./data)
./data/example_data.dat
./data/example_data_in_front_of_building.dat

```
In [10]: # The matrix size has to be known in advance. e.g.320 x 240
         # data = data_preparation_TIPA_protocol('./data/example_data.dat',320,240)
         data = data_preparation_TIPA_protocol('./data/example_data_in_front_of_building.dat',320,240)
         # print(data.time_stamp)
```

Coffee Break (15:00 – 15:30)

PhD studentship available at UCL Computer Science in 2020

Call: talented students are invited to propose a PhD research project in areas related to **machine learning, physiological and affective computing**, with the aim to create novel assistive technology and boost disability innovation.

* You can also apply for the project described below.

Project Title
Mobile thermography-based cardiovascular and cortical imaging for detecting anxiety in hospitalised children

Applications for 2020-21 are now being accepted

http://youngjuncho.com/news/phdstudentship/