Thermal imaging of facial expressions: investigating thermal correlates of Facial Action Units activities

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Thermography for emotions study, why?

**PHYSIOLOGICAL MEASURES**

- Cardiac pulse (ECG)
- Muscles activation (EMG)
- Skin conductance

**THERMAL IMAGING**

- FLIR SC3000
- A NEW PHYSIOLOGICAL MEASURE

- * Non invasive technique
- * Avoids overloading equipment
- * Investigation of original physiological patterns (skin temperatures)
Thermography for emotions study, why?

PUBLIC SERVICES
- Security in airports (thermal scanners for fever screening and detection of stress in terrorists)
- Thermography used by firefighters to see persons through smoke
- Mechanical inspections
- Gas leak

MEDECINE DIAGNOSIS
- Human breath tracking (2)
- Cardiopulmonary tracking (3)
- Muscles troubles (1)

Emotions
- Emotion discrimination (1, 2, 3)
- Deception detection (4)
- Stress detection in human and animals (5, 6, 7)

Our 1st validation study

Goal of this work:
Validating the thermal imaging technique for assessing the fluctuations of facial heat patterns.
Measuring the camera sensitivity to kinetics, intensities and specificities

First interest: facial heat patterns
Emotional facial expressions can be systematically coded using Facial Action Coding System (FACS)
FACS experts as subjects
Thermal correlates of facial action units

http://riendetout.over-blog.org/article-14411041-4.html
Questions and Hypotheses

• **QUESTIONS**
  – **Kinetics**
    Is thermography sensitive to kinetics?
  – **Intensities**
    Is thermography sensitive to intensity?
  – **Specificity**
    Is thermography sensitive to muscles specificity?

• **HYPOTHESES**
  – Each AU has a specific recognizable facial heat pattern associated
  – Temperature changes in specific muscles are correlated with their associated action unit simulation
  – Thermography can be an adapted tool for studying kinetics and intensities of the AUs

Protocol

• 4 FACS experts: 1 man and 3 women from 28 to 51 years old all right-handed except one woman
• 9 different AUs
• 3 intensities: just perceptible / normal / high
• 2 speeds: slow(5sec) / fast(1sec)
• Thermal camera + optical camera
• Head till
## The Action Units

<table>
<thead>
<tr>
<th>AU</th>
<th>DESCRIPTION</th>
<th>MUSCLE</th>
<th>IMAGE</th>
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<tbody>
<tr>
<td>AU1+2</td>
<td>Inner and outer brow raiser</td>
<td>Frontalis</td>
<td>+</td>
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<tr>
<td>AU4</td>
<td>Brow lowerer</td>
<td>Corrugator</td>
<td></td>
</tr>
<tr>
<td>AU5</td>
<td>Upper lid raiser</td>
<td>Levator palpebrae superioris</td>
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<tr>
<td>AU6+12</td>
<td>Cheek raiser and lip corner puller</td>
<td>Orbicularis oculi + zygomaticus major</td>
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<tr>
<td>AU12</td>
<td>Lip corner puller</td>
<td>Zygomaticus major</td>
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<tr>
<td>AU12+25</td>
<td>Lip corner puller and lips part</td>
<td>Zygomaticus major + depressor labii inferioris</td>
<td>+</td>
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<tr>
<td>AU25</td>
<td>Lips part</td>
<td>Depressor labii inferioris</td>
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<tr>
<td>AU9+10</td>
<td>Nose wrinkle and upper lip raiser</td>
<td>Levator labii superioris</td>
<td>+</td>
</tr>
<tr>
<td>AU14</td>
<td>Dimpler</td>
<td>Buccinator</td>
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</table>

[http://www.cs.cmu.edu/afs/cs/project/face/www/facs.htm](http://www.cs.cmu.edu/afs/cs/project/face/www/facs.htm)

## Methods

- **1st step: thermal images registration**
  - Images alignment using similarity criteria
  - Registration using control points and a template constructed from Karolinska mean faces

- **2nd step: two different approaches to answer the questions**
  - Principal Component Analyses (data-driven)
  - Anatomical approach using the ARTANATOMY tool (ROI)

[http://www.artanatomia.net](http://www.artanatomia.net) Victoria Contreras Flores SPAIN 20005
FIRST STEP
Thermal images registration

• Exportation from ThermaCAM
  – Images -> .MAT files

• Reduction of facial images for speed and disk space optimization
  – the 4 FACS experts head should fit into the rectangle during all sequences
  – Chosen size : 210x150

• Facial images extraction and creation of one images array per sequence
  – 238 images for FAST AU sequences
  – 306 images for SLOW AU sequences
  – 1 image each 17ms
Thermal images registration
Facial images normalization

Processing:
0. All images rescaled to 210x150
1. All images of a given sequence aligned on its 1st image
2. All images from all sequences of a given subject aligned on 1st image 1st sequence
3. All images registered on the Karolinska's mean face (man+woman average)

Methods:
Rescaling:
- bilinear interpolation

Alignment:
- MATLAB's optimization routine 'fminsearch'
- MATLAB's spatial transformation routine from control point pairs (with 'lwm' as transformation type)

Registration for inter-subjects normalization:
- MATLAB's spatial transformation routine from control point pairs (with 'lwm' as transformation type)

RESULTS
PROCESSING
SECOND STEP
Data-driven approach
Principal Component Analysis
ROI approach
Anatomically-based
The 2 approaches

**DATA-DRIVEN APPROACH: PCA**
- Representative heat patterns production
  - Principal Components mean grouping by AU using one of these criteria:
    - Components whose eigenvalue>1: our retained criteria
    - Visual selection of interesting components: time-consuming and subjective analysis
    - 90% explained variance: automatic and objective but not as good results as with the eigenvalue criteria
  - Kinetics + phases determination
    - Plot PC grouping same AUs by speed (F/S)
    - 20% extreme curve
  - Intensities
    - Plot factor scores and correlations grouping same AUs by intensity (JP/N/H) + permutations
  - Specificities and Pattern recognition: Are these maps good indicators of the AUs?
    - Correlations between each image of each sequence and each heat pattern maps
    - Non-parametric permutation analysis 10000times

**ROI APPROACH: ANATOMICALLY-BASED**
- Facial ROI definitions
  - Anatomical template creation: ARTANATOMY + previous registration technique
  - Masks creation: MATLAB’s routine ‘roipoly’ on the registered template
  - ROIs-temperature mean under each condition
  - Kinetics + phases determination
    - Plot ROI temperature variations grouping same AUs by speed (F/S)
    - 20% extreme curve
  - Intensities
    - Plot ROI temperature variations grouping same AUs by intensity (JP/N/H) + permutations
  - Specificities and Pattern recognition: Are these ROIs-temperature good indicators of the AUs?
    - Non-parametric permutation analysis 10000times

Baseline mean corrected on registered images

Heat patterns and anatomical ROI

Facial heat patterns

Anatomical ROI
Is thermography sensitive to kinetics?

In literature: onset duration is 0.935 sec (i.e., 55 frames)

**ONSET PHASE** = phase where the muscles are contracting and the appearance of the face changes as the facial action grows stronger.

**APEX PHASE** = phase where the facial action is at its peak and there are no more changes in facial appearance due to this particular facial action.

**OFFSET PHASE** = phase where the muscles are relaxing and the face returns to its neutral appearance.

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-> do not differentiate slow from fast AU
Is thermography sensitive to intensities?

**Principal Component Analysis**

**Is thermography sensitive to muscles specificities?**

Pattern recognition of FAST AU on APEX phase

### Mean correlations and significative differences with mean PC maps

**Permutation 1000x**

**Font**
- Red: significative difference with AU map
- Black: no significative difference

**Fill**
- Brown: muscles from upper part of the face
- Orange: muscles from lower part of the face

### Table of Mean Correlations and Significative Differences

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<td>n.s.</td>
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</tbody>
</table>
Is thermography sensible to muscles specificities?

Pattern recognition of FAST AUs on APEX phase

Mean temperatures and significative differences between AUs
Permutation 1000x

<table>
<thead>
<tr>
<th>ROI</th>
<th>Mean temperatures</th>
<th>Significative differences</th>
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<tbody>
<tr>
<td>AU12</td>
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<td>-3.894e-007 p&lt;0.001</td>
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<td>-3.894e-007 n.s</td>
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<td>AU14</td>
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<td>AU9+10</td>
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</table>

Is thermography sensible to muscles specificities?

Pattern recognition - SLOW AUs

PCA - Correlations

ROI
Conclusions

**PCA**

*Is thermography sensitive to kinetics?*
In general yes.
Possibility to determine a precise APEX phase
Problem with: AU12+25 (factor scores) / AU9+10 (in both methods)

*Is thermography sensitive to intensities?*
In general yes.
Possibility to determine a precise APEX phase
Problem with: AU12 (factor scores) / AU14 (factor scores) / AU12+25 (correlations) / AU4 and 5 (missing significant PC @ JP intensity)

*Is thermography sensitive to muscles specificities?*
In general yes.
Creation of specific facial heat pattern associated to each AU
Eigenvalue criteria better than 90% of variance criteria for constructing these maps.
Problem with: AU12 confusion with Map AU14 @ fast / AU12+25 confusion with Map AU14 @ fast / AU12+12 confusion with Map AU12+25 and AU14 @ slow / AU12+25 confusion with Map AU5 @ slow

**ROI**

*Is thermography sensitive to kinetics?*
In general yes.
Possibility to determine a precise APEX phase
Problem with: AU25

*Is thermography sensitive to intensities?*
In general yes.
Problem with: AU25

*Is thermography sensitive to muscles specificities?*
In general yes.
Zygomaticus and corrugator contractions seem to be associated with an increase of temperature while frontalis activations is linked with a decrease of temperature
Problem with: AU12 confusion with Map AU14 @ fast & slow / AU12+25 confusion with ROI14, 1+2 @ fast and ROI12 and 25 not recognized / AU4 confusion with ROI6 @ fast / AU1+2 confusion with ROI9+10 @ slow

Discussion

Possible reasons for decreasing temperature in frontalis area?

- Inter-individual anatomic differences:
  - Presence and position of arterial veins in the frontal head
  - Size of brows (cold area) passing on the frontalis zone studied while raising brows
  - Hairs can be present in the top of the frontalis area
  - Crumpling of the skin while contracting the frontalis

- AU simulation performances:
  - The results could depend on the quality of the simulation.
  - Subject 4 was the FACS teacher and has bigger activation and clear corrugator heating and frontalis colding but she was also closer from the camera than other and simulated less AUs.
  - Possible overlap between AU9+10 / AU5 / AU1+2, difficult task
Thermography proved to be an adaptive tool for detecting movements in the face.

**PCA or Anatomical approach, most appropriate method?**
- Anatomical approach seems to be more sensitive to kinetics and intensities.
- PCA is a global method without a-priori while anatomically-based approach implies some presumptions and appropriate ROIs selection and these ROIs are greatly influence by movements of facial skin.
- PCA with eigenvalue criteria give facial heat patterns associated to AUs.

PCA and anatomical approaches seem to be complementary, PCA can be used for a 1st exploratory analysis, while anatomical method can further investigate regions appearing on PCA for differentiating for example AU6+12 from AU12 (smiles).

**Next investigations:**
- Is global facial temperature an indicator of real emotions?
  - Experiment with spontaneous emotions with odors and images.
- Is it possible to differentiate what is muscles movement warming from what is emotion-induced skin warming?

These last results that can differentiate AU12, from AU4, AU1+2 and 9+10 let us believe that spontaneous emotions will be detectable with this thermal imaging technique.

---

**General conclusion**

Thank you for your attention.

Sylvain Delplanque
Patrik Vuilleumier
Klaus Scherer
Karim N’Diaye
Lucas Tamarit
David Sander
Thermal images registration

First data exploration – mean corrected

The 2 methods comparison

SLOW AUs and approach emotions

<table>
<thead>
<tr>
<th>SLOW</th>
<th>ROI AU12</th>
<th>ROI AU9+10</th>
<th>ROI AU4</th>
<th>ROI AU1+2</th>
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<tr>
<td>AU12 happiness</td>
<td>0.32464</td>
<td>0.23507</td>
<td>0.04703</td>
<td>0.03964</td>
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<tr>
<td>AU9+10</td>
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<td>0.04703</td>
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</table>

Happiness

- AU12: 0.32464, n.s
- AU9+10: 0.23507, p<0.001
- AU4: 0.04703, p<0.001
- AU1+2: 0.03964, p<0.001

Disgust

- AU12: 0.34757, p<0.001
- AU9+10: 0.23507, n.s
- AU4: 0.01874, p<0.001
- AU1+2: -0.02854, p<0.001

Anger

- AU12: 0.27708, p<0.001
- AU9+10: 0.17285, p<0.001
- AU4: 0.01874, n.s
- AU1+2: -0.15936, p<0.001

Surprise

- AU12: 0.30747, n.s
- AU9+10: 0.17285, p<0.001
- AU4: 0.01874, p<0.001
- AU1+2: 0.20774, n.s
More PCA Results

Is thermography sensitive to kinetics?
Using Factor Scores
Principal Component Analysis

Is thermography sensitive to intensities?
Using Factor Scores

- Mixing slow and fast AUs
Principal Component Analysis

*Is thermography sensible to kinetics?*

Using Images Similarity Metric (*correlation*)

---

*Is thermography sensible to intensities?*

Using Images Similarity Metric (*correlation*) during FAST AUs
Principal Component Analysis

**FAST AUs correlations with MAP AU in time**

- **Is thermography sensible to muscles specificities?**

Pattern recognition of **SLOW** AU on APEX phase

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<tr>
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<th>MAP AU12+12</th>
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**Mean correlations and significative differences with mean PC maps**

**Permutation 1000x**

**FONT**
- **Red** significative difference with AU map
- **Black** no significative difference

**FILL**
- **Brown** muscles from upper part of the face
- **Orange** muscles from lower part of the face
Principal Component Analysis

SLOW AUs correlations with MAP AU in time

MORE ANATOMICAL RESULTS
Anatomically-based approach

Is thermography sensible to kinetics?

(ZYGOMATICUS MAJOR
Temperature Means under AU12

0.5 1 1.5 2

Temperature variation in degrees

CORRUGATOR SUPERIOR
Temperature Means under AU4

0.5 1 1.5 2

Temperature variation in degrees

FRONTALIS
Temperature Means under AU1+2

0.5 1 1.5 2

Temperature variation in degrees

ORNICULARIS OCULI
Temperature Means under AU9+12

0.5 1 1.5 2

Temperature variation in degrees

BUCCINATOR
Temperature Means under AU6

0.5 1 1.5 2

Temperature variation in degrees

LEVATOR PALPEBRAE SUPERIORIS
Temperature Means under AU5

0.5 1 1.5 2

Temperature variation in degrees

DEPRESSOR LABII INFERIORIS
Temperature Means under AU9

0.5 1 1.5 2

Temperature variation in degrees

LEVATOR LABII SUPERIORIS
Temperature Means under AU9+10

0.5 1 1.5 2

Temperature variation in degrees

Anatomically-based approach

Is thermography sensible to intensities?

0

1

2

3
Principal Component Analysis

FAST AUs temperature means in time

Anatomically-based approach

Is thermography sensible to muscles specificities?

Pattern recognition on APEX phase SLOW AUs

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<th>ROI AU25</th>
<th>ROI AU14</th>
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Mean temperatures and significative differences between AUs

Permutation 1000x

FONT
Red: significative difference with AU map
Blue: no significative difference
Brown: muscles from upper part of the face
Orange: muscles from lower part of the face
Principal Component Analysis

SLOW AUs temperature means in time