Emotion assessment from physiological signals for adaptation of games difficulty

Thierry Pun
Computer Vision and Multimedia Laboratory
University of Geneva, Switzerland

Based on:
Objectives and hypotheses
Acquisition protocol
Feature extraction
  • EEG's
  • Peripheral signals
Analysis of questionnaires
Analysis of physiological features
Classification
  • Features selection
  • Peripheral signals, EEG's
  • Fusion
  • Effect of trial duration
Game over
Conclusions and future work
Objectives and hypotheses

“Flow of experience” theory [Csikszentmihályi]
- complete engagement in task, positive feelings, loss of sense of time;
- appears when the challenge of a task meets the “user’s” skill.

[Diagram showing the relationship between challenge, competence of the player, flow channel, anxiety, engagement, boredom, and change in player’s competence and game’s difficulty.]
Objectives and hypotheses

To maintain the level of involvement and pleasure by:
- assessing the emotional state of user through monitoring of physiological signals;
- controlling the difficulty of the task to influence challenge;
- here: task is a game, Tetris.

Why Tetris?
- known to elicit strong emotional responses;
- possibility to control the difficulty of the task (25 speed levels);
- well known so different gamer competences available;
- can be played with one hand.
Objectives and hypotheses

Hypotheses

- H1: playing at different levels of difficulty induces one of 3 emotional states (boredom, engagement, anxiety);
- H2: as the skill increases, the player will switch from the engagement state to the boredom state;
- H3: these emotional states can be assessed using central and peripheral physiological signals.

Validation:
- from questionnaires and physiological data analysis;
- 20 participants (incl. 14 with EEG recordings).
Acquisition protocol

Determination of 3 gaming conditions (threshold method):
- medium (engagement) : levels 11 to 20;
- hard (anxiety) : medium level + 8, max 25;
- easy (boredom) : medium level – 8, min 5.

Schedule of the protocol:

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1'30</td>
<td>Baseline Stay calm and relax</td>
</tr>
<tr>
<td>1'35</td>
<td>Play the tetris game at one of the three states</td>
</tr>
<tr>
<td>2'35</td>
<td>Answer questionnaire</td>
</tr>
</tbody>
</table>

Random permutation of difficulty for each participant
Acquisition protocol

Physiological signals from:
- peripheral nervous system: GSR, blood pressure, respiration, temperature;
- central nervous system: EEG, 19 electrodes (Bioesmi Active II).

Why?
- physiological signals cannot be easily faked;
- part of emotional processes are cognitive;
- fusion of modalities improves results.
Feature extraction – EEG's

**EEG features:**
- energy in 3 bands alpha, beta, theta, related to emotional processes (e.g. alpha lateralization for approach-withdrawal);
- \( EEG_W \), related to workload, engagement, attention, fatigue.

<table>
<thead>
<tr>
<th>Feature for electrode ( i )</th>
<th>Frequency band</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \theta_i )</td>
<td>4-8 Hz</td>
</tr>
<tr>
<td>( \alpha_i )</td>
<td>8-12 Hz</td>
</tr>
<tr>
<td>( \beta_i )</td>
<td>12-30 Hz</td>
</tr>
</tbody>
</table>

\[
EEG_W = \log \left( \frac{\sum_{i=1}^{K} \beta_i}{\sum_{i=1}^{K} \theta_i + \alpha_i} \right)
\]
Feature extraction - Peripheral

**GSR:**
- mean value;
- mean of derivative;
- sum of negative derivatives;
- % of negative samples in derivative.

**Respiration:**
- main frequency;
- max – min (range);
- standard deviation.

**Temperature:**
- mean value;
- mean of derivative.

**Blood pressure:**
- mean value;
- standard deviation.

**Heart rate:**
- mean value;
- heart rate variability;
- variance;
- mean of derivative.
# Feature extraction - Peripheral

<table>
<thead>
<tr>
<th>Peripheral signal</th>
<th>Feature name</th>
<th>Extracted feature</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSR</td>
<td>$\mu_{GSR}$</td>
<td>Mean skin resistance</td>
<td>Estimate of general arousal level</td>
</tr>
<tr>
<td></td>
<td>$\delta_{GSR}$</td>
<td>Mean of derivative</td>
<td>Average GSR variation</td>
</tr>
<tr>
<td></td>
<td>$f_{\text{DecRate}}^{GSR}$</td>
<td>Mean of derivative for negative values only</td>
<td>Average decrease rate during decay time</td>
</tr>
<tr>
<td></td>
<td>$f_{\text{DecTime}}^{GSR}$</td>
<td>Proportion of negative samples in the derivative vs. all samples</td>
<td>Importance and duration of the resistance fall</td>
</tr>
<tr>
<td></td>
<td>$f_{\text{NbPeaks}}^{GSR}$</td>
<td>Number of resistance falls in the signal</td>
<td>-</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>$\mu_{BVP}$</td>
<td>Mean value</td>
<td>Estimate of general pressure</td>
</tr>
<tr>
<td></td>
<td>$\sigma_{BVP}$</td>
<td>Standard deviation</td>
<td>Blood pressure variation</td>
</tr>
</tbody>
</table>
### Feature extraction - Peripheral

<table>
<thead>
<tr>
<th></th>
<th>( \mu_{HR} )</th>
<th>Mean of heart rate</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta_{HR} )</td>
<td>Mean of heart rate derivative</td>
<td>Estimations of heart rate variability</td>
<td></td>
</tr>
<tr>
<td>( \sigma_{HR} )</td>
<td>Standard deviation of heart rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f_{LF}^{HR} )</td>
<td>Energy in 0.05Hz-0.15Hz band</td>
<td>Parasympathetic and sympathetic activity</td>
<td></td>
</tr>
<tr>
<td>( f_{HF}^{HR} )</td>
<td>Energy in 0.15Hz-1Hz band</td>
<td>Parasympathetic activity</td>
<td></td>
</tr>
<tr>
<td>( f_{LF/HF}^{HR} )</td>
<td>Ration of energy in the LF and HF bands</td>
<td>Ratio of parasympathetic and sympathetic activity</td>
<td></td>
</tr>
<tr>
<td>Respiration</td>
<td>( f_{R_{\text{Resp}}} )</td>
<td>Frequency with the highest energy</td>
<td>Respiration rate</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{R_{\text{Resp}}} )</td>
<td>Standard deviation</td>
<td>Variation of the respiration signal</td>
</tr>
<tr>
<td></td>
<td>( f_{DR_{\text{Resp}}} )</td>
<td>Maximum value minus minimum value</td>
<td>Dynamic range or greatest breath</td>
</tr>
<tr>
<td>Skin Temperature</td>
<td>( \mu_{\text{Temp}} )</td>
<td>Mean value</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>( \delta_{\text{Temp}} )</td>
<td>Mean of derivative</td>
<td>Estimation of temperature variability</td>
</tr>
</tbody>
</table>
Analysis of questionnaires

**Description:**
- 30 questions, with Likert scale ranging from 1 to 7;
- related to emotions: “I was stressed”, “I had pleasure”, ...
- related to involvement: “I was focused on the game”, “I was motivated”, ...

**30D factor analysis to obtain axes with maximum variance:**
- 56% of variance with first 2 components;
- 1st component >0 correlation with pleasure, interest, motivation, focus: **valence**
- 2nd component >0 correlation with excitation, pressure, <0 correlation with calm, control: **arousal**
Analysis of questionnaires

Results from participants:
- lower valence felt in the easy and hard conditions than in the medium one;
- the more difficult the game is, the higher is the arousal.

Three conditions do exist:
⇒ **H1 validated by self-assessments**
Trend on the most relevant physiological features, easy-to-medium, and medium-to-hard conditions:

<table>
<thead>
<tr>
<th>Feature</th>
<th>F-value</th>
<th>p-value</th>
<th>Trend of the mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_{GSR}$</td>
<td>4.4</td>
<td>0.01</td>
<td>↓→</td>
</tr>
<tr>
<td>$\delta_{GSR}$</td>
<td>2.7</td>
<td>0.07</td>
<td>↓→</td>
</tr>
<tr>
<td>$f_{DecRate,GSR}$</td>
<td>3.1</td>
<td>0.05</td>
<td>↓→</td>
</tr>
<tr>
<td>$f_{DecTime,GSR}$</td>
<td>6.7</td>
<td>&lt; 0.01</td>
<td>↑↓</td>
</tr>
<tr>
<td>$J_{GSR,Peaks}$</td>
<td>18.3</td>
<td>&lt; 0.01</td>
<td>↑↓</td>
</tr>
<tr>
<td>$\mu_{HR}$</td>
<td>3.4</td>
<td>0.04</td>
<td>↑↓</td>
</tr>
<tr>
<td>$f_{LF,HR}$</td>
<td>2.4</td>
<td>0.09</td>
<td>↓↑</td>
</tr>
<tr>
<td>$\sigma_{Resp}$</td>
<td>5.8</td>
<td>&lt; 0.01</td>
<td>↑↓</td>
</tr>
<tr>
<td>$\mu_{Temp}$</td>
<td>9.4</td>
<td>&lt; 0.01</td>
<td>↓↓</td>
</tr>
<tr>
<td>$\delta_{Temp}$</td>
<td>10</td>
<td>&lt; 0.01</td>
<td>↓↓</td>
</tr>
</tbody>
</table>

- increase for easy-to-medium,
- stable for medium-to-hard
Results from peripheral physiological features:
- increase of arousal btw. medium and hard conditions but less than btw. the easy and medium conditions;
- increased arousal for increasing game difficulty;
- peripheral physiological data also supports H1.
EEG features:
- alpha-band: no difference btw. the 3 conditions;
- beta and theta bands: several features show differences;
- EEG_W:
  - median increases as difficulty increases;
  - significant differences btw. easy and hard conditions, medium and hard conditions;
  - median not higher for medium condition: EEG_W more related to workload than engagement;
- EEG data also supports H1.
Analysis of physiological features

*EEG*\_W* values for the 3 gaming conditions:

![Box plot showing EEG\_W values for easy, medium, and hard conditions. The plot indicates significant differences between conditions with *F* values and p-values.](image)
Analysis of physiological features

H2: as skill increases, switch from engagement to boredom.

Test on data from 2 consecutive medium-condition games:
• questionnaires: significant decrease for questions “I had pleasure to play” and “I had to adapt to the interface”;
• peripheral signals: decrease in GSR peaks, increase in average temperature and average derivative of temperature.

Conclusions:
• decrease of arousal and increase in skills btw. successive games;
• tends to validate H2, but is the game boring or is the competence increased?
Classification

Classifiers:
• LDA – Linear Discriminant Analysis;
• QDA – Quadratic Discriminant Analysis;
• SVM – Support Vector Machines with RBF kernel.

Ground truth: 3 difficulties corresponding to 3 emotional states.

Remarks:
• "small" number N of users (20): classifiers trained on N-1, tested on 1 (cross-validation);
• player independent.
Classification

Features selection:
- FCBF - Fast Correlation Based Filter: removes features having low correlation with class concept;
- ANOVA;
- SFFS – Sequential Floating Forward Search: evaluates feature subsets.

Fusion of EEG and peripheral signals:
- at the decision level;
- Bayes belief integration: classifiers weighted by their average error.
Peripheral features selection (nr. of times a feature was selected):

**GSR features**

- FCBF
- ANOVA
- SFFS
EEG features selection (nr. of times a feature was selected):
Peripheral features classification, confusion matrix for “FCBF + QDA”:

<table>
<thead>
<tr>
<th>True</th>
<th>Estimated</th>
<th>Easy (Boredom)</th>
<th>Medium (Engagement)</th>
<th>Hard (Anxiety)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy (Boredom)</td>
<td>80%</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Medium (Engag.)</td>
<td>37%</td>
<td>33%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Hard (Anxiety)</td>
<td>21%</td>
<td>19%</td>
<td>60%</td>
<td></td>
</tr>
</tbody>
</table>
EEG features classification, confusion matrix for “ANOVA + LDA”:

<table>
<thead>
<tr>
<th>True</th>
<th>Estimated</th>
<th>Easy (Boredom)</th>
<th>Medium (Engagement)</th>
<th>Hard (Anxiety)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy (Boredom)</td>
<td>57%</td>
<td>43%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Medium (Engag.)</td>
<td>21%</td>
<td>50%</td>
<td>29%</td>
<td></td>
</tr>
<tr>
<td>Hard (Anxiety)</td>
<td>19%</td>
<td>19%</td>
<td>62%</td>
<td></td>
</tr>
</tbody>
</table>
**Classification – Fusion**

**Fusion** of EEG and peripheral features with Bayes Belief Integration:
- 5% increase of average accuracy;
- 2% (7%) increase for the easy (hard) conditions;
- 11% decrease for medium condition comp. with EEG’s, but 6% increase comp. with peripherals features;
- only 4% error in classifying easy as hard, or hard as easy.

<table>
<thead>
<tr>
<th>True</th>
<th>Estimated</th>
<th>Easy (Boredom)</th>
<th>Medium (Engagement)</th>
<th>Hard (Anxiety)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy (Boredom)</td>
<td>82%</td>
<td>14%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>Medium (Engag.)</td>
<td>29%</td>
<td>39%</td>
<td>32%</td>
<td></td>
</tr>
<tr>
<td>Hard (Anxiety)</td>
<td>4%</td>
<td>27%</td>
<td>69%</td>
<td></td>
</tr>
</tbody>
</table>
Classification accuracy as a function of trial duration: EEG features are more robust for short-term assessment.
GSR and HR in the 5s following game over:
Game over

Possible interpretations:

- GSR: low for high difficulty, which might indicate more arousal and stress to start a new game known to be difficult;
- HR: often higher for unpleasant stimuli, which might indicate here deception of losing a game at medium difficulty.

Thus different patterns of peripheral activity exist btw. sessions where users reported:

- higher motivation and pleasantness, or
- high pressure and less motivation.

Could be used to distinguish engaged from stressed states.
Conclusions and future work

Research hypotheses:
• H1 verified: playing Tetris at different levels of difficulty induces different emotional states;
• H2 somehow verified: is the change of emotional state due to boredom, or to an increase of competence?
• H3 somehow verified: accuracy >> chance levels, interest of fusion, of EEG’s for short-term analysis.

Emotional states:
• easy condition: boredom (low valence, arousal, and motivation, and high dominance);
• medium condition: engagement (high arousal-valence);
• hard condition: anxiety (neg. valence, low dominance, high arousal until gives up).
Conclusions and future work

Others:
• engagement can decrease if game difficulty does not change;
• analysis of game-over: distinct patterns of GSR and HR in 5s following end-game (to distinguish engagement from stress?).

Future work:
• increase classification accuracy: feature selection, player dependant framework;
• fusion with other modalities, e.g. voice, body;
• user and context modeling: goals, personalities;
• temporal information: mood, previous emotional state and game events;
• develop affective Tetris (and other games).