Quantification of Brain Responses for Neurofeedback Games in 3D Virtual Environments

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Background

BCI System

Figure 1: General architecture of an online brain-computer interface.
Thoughts power (BCI applications)
Background

- Neurofeedback
Medical Applications of Neurofeedback Games

- Treatment as alternative to medication and even surgery (Attention Deficit Hyperactive Disorder, sleep disorder, depression treatment, Generalized anxiety disorder, etc.)
- Rehabilitation with music therapy or 3D VR games therapy (pain management, stroke recovery, cognitive impairment due to surgery, etc.)
- Prevention of diseases of psychosomatic origin with music therapy based on emotion induction or 3D VR games therapy
Motivation

- Equipment
  - To derive or add the content into game/Co-space based on the user’s EEG recognition.
  - Affordable electro-encephalograph cap devices with wireless data transmission.

**PET 2.0**
- 2 channels with 29bit AD
- 200Hz sampling frequency

**Emotiv**
- 14 channels with 16bit AD
- 128Hz sampling frequency
Research Objective

- Research on mathematical models and algorithms about quantification of levels of the user’s engagement.
- Propose novel neurofeedback methods and algorithms that quantify the states of the brain automatically in real time.
- Analysis of algorithm performance, accuracy and efficiency with less electrodes.
- Propose and implement experiments on emotion/arousal level recognition.
- Research and development of EEG-based 3D games for medical applications.
- Novelty of the games: therapy integrated in the collaborative game through immersive 3D environment.
Brain Maps

Frontal Lobe
- Arousal reaction to self and environment
- Executive functioning and judgments
- Emotional response and stability
- Language usage

Parietal Lobe
- Virtual and touch perception
- Object Manipulation

Occipital Lobe
- Virtual perception

Temporal Lobe
- Auditory perception
## EEG Signals

- **Delta band (2 - 4Hz)**
  - In Babies EEG
  - When adult is sleeping

- **Theta band (4 - 8Hz)**
  - In young children EEG
  - When adult is idling

- **Alpha band (8 - 12Hz)**
  - Relax
  - Closing the eyes

- **Beta band (12 - 30Hz)**
  - Alert/working
  - Active, busy or anxious thinking, active concentration

- **Gamma band (above 30Hz)**
  - Cognitive or motor functions
Previous Work

- Yerkes-Dodson Law

The Yerkes-Dodson Law illustrates that performance in a task is optimal at a medium level of arousal, with decreased performance at both low and high levels of arousal. The diagram shows that for easy tasks, the optimum level of CNS arousal is higher, while for hard tasks, it is lower. This suggests that the optimal level of arousal depends on the difficulty of the task.
Previous Work

- Emotion Classification
## Emotion Classification

<table>
<thead>
<tr>
<th>Author</th>
<th>Brain State</th>
<th>Classifier</th>
<th>Feature</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guillaume Chanel et al. 2008</td>
<td>Calm, Happy, Unhappy</td>
<td>LDA, Linear SVM</td>
<td>EEG STFT, EEG MI, Peripheral signals</td>
<td>80%</td>
</tr>
<tr>
<td>Guillaume Chanel et al. 2008</td>
<td>Boredom, Engagement, Anxiety</td>
<td>Radial Basis Function SVM</td>
<td>Peripheral signals</td>
<td>70%</td>
</tr>
<tr>
<td>Christos A. Frantzidis. 2008</td>
<td>Joy (LP), Happy (HP), Melancholy (LN), Fear (HN)</td>
<td>Neural Network</td>
<td>Skin conductivity response, ERP, delta frequency</td>
<td>80%</td>
</tr>
</tbody>
</table>
Previous Work

- Engagement management in Game

Score: 591
Level: 1

Block

Next:

Anxiety (negative excited)
Flow channel
Engagement (positive excited)
Boredom (negative calm)

Challenge / difficulty of the game

Competence of the player
Previous Work

- Neurofeedback

Somatic Vision Inc.  Neuroflash Team
## Previous Work

### Neurofeedback Treatment for ADHD

<table>
<thead>
<tr>
<th>Application</th>
<th>Method</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADHD</td>
<td>Theta/beta Frequency Band Training</td>
<td>Barry, 2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monastra, 2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hou, 2008</td>
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<td></td>
<td></td>
<td>Yeongjoon Gil, 2009</td>
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<tr>
<td></td>
<td>SCP Training</td>
<td>Kropotov, 2005</td>
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<tr>
<td></td>
<td></td>
<td>Strehl, 2009</td>
</tr>
<tr>
<td></td>
<td>Virtual Reality Training</td>
<td>BAEK-HWAN CHO, 2002</td>
</tr>
</tbody>
</table>
## Neurofeedback

Treatment for other disorders

<table>
<thead>
<tr>
<th>Application</th>
<th>Method</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep Disorder</td>
<td>QEEG Neurofeedback</td>
<td>Ibric and Hudspeth, 2003</td>
</tr>
<tr>
<td>Communication and Socialization Problem</td>
<td>QEEG Neurofeedback</td>
<td>Linden, 2004</td>
</tr>
<tr>
<td>Pain Management</td>
<td>Alpha/Theta Frequency Band Training, Relaxation Strategy</td>
<td>Batty, 2006</td>
</tr>
<tr>
<td>Addiction</td>
<td>Alpha/Theta Frequency Band Training</td>
<td>Loytsker, 2002</td>
</tr>
<tr>
<td>GAD</td>
<td>Alpha Suppression and Symmetry Training</td>
<td>Kerson, 2002</td>
</tr>
</tbody>
</table>
## Neurofeedback

**Application for normal person**

<table>
<thead>
<tr>
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<th>Method</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artistic Ability</td>
<td>Alpha/Theta Frequency Band Training</td>
<td>John Gruzelier, 2009</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Gamma Frequency Band Training</td>
<td>Keizer, 2009</td>
</tr>
</tbody>
</table>
Multidisciplinary research: study of brain mapping, emotions/arousal experiments, BCI system, neurofeedback games, EEG-based medical application, neurofeedback methods and algorithms

Research on Renyi based Fractal Dimension Model and algorithms

Propose novel neurofeedback methods and algorithms

Propose and Develop EEG-based 3D games for medical applications with integrated therapy
Game Structure

Objective:

1. Immersive 3D environment for feedback and therapy
2. Recognition of the brain state from EEG signals
3. Adaptive games: modify the level according to the user’s emotion/arousal state of the brain
Fractal Dimension Model

- The fractal dimension is a measurement of complexity. The changes of pattern embedded in signal can be noticed by changes in FD.
- The higher fractal dimension is, the more the structure observed proves “irregular”, conversely a low dimension will characterize a more regular structure.
- In 2-D space the FD should be limited in this region $1 \leq \text{FD} \leq 2$.
- EEG signal has fractal nature. Change in EEG signal can be noticed by change in FD.
Fractal Dimension Model

Different Fractal Dimensions:

- Hausdorff Dimension
- Information Dimension
- Correlation Dimension
- Entropy Fractal Dimension
- Generalization by Renyi model

Experiment Method:

- Different dimensions, dimension spectra, sample size for sliding window
- FD for different frequency bands connected to different states of the brain
- Spatio-temporal analysis of FD value through visual mapping
Outline

- Background & Motivation
- Research Objective
- Previous Works
- Proposed Research Method
- State of Project
State of Project

The following work completed:

1. Review on previous work on brain mapping, emotions/arousal experiment, BCI, neurofeedback
2. Research on Renyi based Fractal Dimension Model
3. Study, Implementation, and Analysis of Fractal Dimension Algorithms: Higuchi, Box-counting method
4. Development of concentration/relaxation 2D game with Higuchi/Box-counting fractal dimension algorithms
5. Collaboration with Tan Tock Seng Hospital (TTSH) on pain management
Thank you!

Q&A