Fractal Dimension Based Neurofeedback

Wang Qiang
Electrical & Electronic Engineering, NTU
Institute for Media Innovation, NTU
Group

Prof. Olga Sourina
Background

**EEG**

![EEG signal and power spectral density graphs](image)
Background

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
Background

- BCI application in Game

- P300
- Motor Image
- Frequency bands power
- SSVEP
Background

**Neurofeedback**

- Feature Extraction
- Classification
- Command Mapping
- Preprocessing
- Mental Process
- Signal Acquisition
- Stimuli (visual, audio, etc)

![Diagram of Neurofeedback Process]

- Desktop Computer
- Player
- Emotiv EEG Device
- Wireless Communication
- Desktop Computer
Background

Psychological Disorders

Attention Deficit Hyperactivity Disorder (ADHD) [1]
Patients have problem in attention and focus.

Autistic spectrum Disorders (ASD) [2]
Patients have problem in social interaction and communication

Substance Use Disorders (SUD)[3]
Abuse of alcohol or drug


Motivation

- One Channel EEG
Motivation

- Algorithms

- Application Fields
Research Objective

- **Attention Level Recognition Stage**
  - Researching nonlinear EEG features for attention level recognition to replace the linear EEG feature.

- **Neurofeedback Implementation Stage**
  - Implement 2D and 3D neurofeedback games based on previous findings in EEG feature.

- **Real-world Application Stage**
  - Expanding the application field from psychological disorder treatment to normal personal applications.
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 value.
- 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 $1 \leq \text{FD} \leq 2$.
Research Method

- **Box-counting Method:**
  - In box-counting method[1], the fractal dimension value is evaluated from the time-amplitude space directly by counting the normalized boxes occupied by the signals. N(d) is proportional to d^{-FD} and the best line fitting method was also used to calculate the fractal dimension value after counting the box.

Higuchi Method:

In Higuchi Method[1], m-dimension phase space is reconstructed by embedding time-delay information, i.e. construct poly-phase subsequences from the recording signals. The capacity number occupying the space is calculated according the length over the subsequences. $L(k)$ is proportional to $k^{-FD}$. Fractal dimension value can be calculated by the least-square linear best fitting line procedure.

\begin{align}
X^m_k : x(m), x(m+k), x(m+2k), \ldots, x(m+\text{int}\left[\frac{N-m}{k}\right]k) \quad (1)
\end{align}

\begin{align}
L_m(k) = \frac{1}{k}\left[\sum_{i=1}^{\text{int}\left(\frac{N-m}{k}\right)} |x(m+ik) - x(m+(i-1)k)| \right] \frac{N-1}{\text{int}\left(\frac{N-m}{k}\right)k} \quad (2)
\end{align}

Comparison:
- **Computational Cost:**
  Box-counting method is quite faster than Higuchi method.
- **Accuracy:**
  Higuchi method is more accurate than Box-counting method.
Experiment Setting up:

- Hardware: Emotiv EEG device. (128 Hz sampling frequency, 16-bit resolution)
- Electrodes: O1 position according to the 10-20 international system. (Occipital Lobe)
- Subjects: 5 subjects aged from 22 – 30.
- Brain state: Relax(Distraction State) vs. concentration (working math problem).
Research Method

- **ROC[1] curve illustration:**

![ROC curve illustration](image)

---

Research Method

- **Roc Curves for 5 subjects in Concentration Experiments**

(a) Subject 1

(b) Subject 2

(c) Subject 3

(d) Subject 4

(e) Subject 5
## Comparison for 4 methods in brain state recognition

<table>
<thead>
<tr>
<th></th>
<th>Higuchi</th>
<th>Box-counting</th>
<th>Brain Rate [1]</th>
<th>θ/β ratio [2]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>mean</td>
<td>0.8811</td>
<td>0.8654</td>
<td>0.8493</td>
</tr>
<tr>
<td></td>
<td>var</td>
<td>0.0077</td>
<td>0.0140</td>
<td>0.0078</td>
</tr>
<tr>
<td><strong>Best Threshold</strong></td>
<td>mean</td>
<td>1.9331</td>
<td>1.6048</td>
<td>15.8071</td>
</tr>
<tr>
<td></td>
<td>var</td>
<td>0.0025</td>
<td>0.0022</td>
<td>35.05</td>
</tr>
<tr>
<td><strong>Time Consuming</strong></td>
<td>mean</td>
<td>0.0172</td>
<td>0.0050</td>
<td>0.0035</td>
</tr>
</tbody>
</table>


Game Structure

Objective:

- Immersive 2D or 3D environment for feedback and therapy
- Recognition of the concentration state from EEG signals
- Generate visual feedback according to the brain state.
Research Method

- Neurofeedback Game

(a) “Dancing Robot” screenshot

(b) “Brain Chi” screenshot

(c) “Pipe” screenshot

(d) “Escape” screenshot
Outline

- Background & Motivation
- Proposed Research Method
- Conclusion and future work
In this research, we studied fractal dimension model and implemented the neurofeedback algorithm based on Higuchi method and box-counting method.

Fractal dimension model was applied in brain states (concentration and relax) recognition and been proven better than other EEG linear features.

We proposed and implemented the original neurofeedback 2D game “Brain Chi”, “Pipe” and 3D game “Dance Robot”, “Escape” based on fractal dimension model that could be used for entertainment.
Future work

- Implement more nonlinear EEG features like dynamic analysis and compare the results with fractal dimension model.

- Extend the fractal dimension model to Renyi Entropy based fractal dimension model. Proposed our own method to calculate the FD value.

- Combine the fractal dimension model with the classical Neurofeedback algorithm. Employ the fractal dimension model in each EEG frequency band individually.

- Apply the neurofeedback game based on fractal dimension model in pain management.

- Construct database based for reference on fractal dimension.


Q & A

Thank you very much!