A Low-Cost EEG System-Based Hybrid Brain-Computer Interface for Humanoid Robot Navigation and Recognition

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Prior Studies of BCI @Everyday Life

BCI @Everyday Applications

- Mobile phone interface (2010) [3]
- Humanoid robot control, navigation [6, 7, 8, 9]
- Controller for the motion-disabled [10]
- How usable is SSVEP BCI? [12]

BCI @Complex Tasks

- Humanoid navigation [7-9]
- Humanoid of many DOF’s control [26]

Complex tasks and everyday usefulness have been studied independently. Time to put them together!
Does cheap, accessible BCI promise to help people with daily tasks?
How Cheap Is “Cheap”*?

Emotiv Epoc Headset, $800
“...Dense array, high quality, raw EEG data”
“Detects Facial Expressions, Performance and Emotion Metrics, and Mental Commands”
“14 EEG channels plus 2 reference channels... optimal positioning for accurate spatial resolution”

Nao Evolution, $8,845
- 25 DOF
- Vision
- Contact Sensors: Chest Button, Foot Bumper, Tactile Head, Tactile Hand

< $10k system, upper-low-tier BCI

* Paper officially uses “low-cost.”
Guiding Criterion

- (1) Tackle a realistic, complex task, using hybrid BCI with
- (2) Accessible (cheap, user-friendly) equipment, and
- (3) High accuracy, realistic performance

The robot system is successful if it:

- Realistically performs the complex task
- Simplifies the complex task

Success means low-cost hybrid BCI can perform multiple tasks with a natural, robot-embodying feel for the user.
Task

**User:** Navigate a maze to the end. When you see fruits, pick your favorite.

**Robot:** Make all adjustments necessary to do exactly what the user wants.
Environment
Design
The User

Example User

Navigating

Recognizing Fruit

Picking Fruit

User's View

- Seated
- Headset
- Screen visuals from robot

Fruit Selection

1. Robot explores.
2. Object is detected.
3. Robot head turns.
4. Recognition mode begins.
5. Readiness session begins.
The Robot Agent

- Navigation/exploration (SSVEP & ERD/ERS)
- Recognition (Image processing)
- Recognition (P300)

Yes, I want the apple.
System Architecture
System Architecture

P300: decision-making signal
System Architecture
Autonomous (User-Independent) Steps

- Physical adjustments

If head & body not aligned, turn body to align to head direction

Return

Body Turn

- if head not aligned, turn head to align to head direction

Return

Idle

Forward Walk & SSVEP off

Stop & SSVEP on

if left, turn head to the left
elseif right, turn head to the right

Head Turn

SSVEP

ERD
ERD Steps

ERD: Event-related desynchronization
SSVEP Steps

@ Exploration: L vs R Head Turn

SSVEP: Steady State Visually Evoked Potential
Evaluation: Quantitative Metrics

Seven metrics tracked over course of task:

1. Time
2. Distance travelled
3. Number of steps forward
4. Number of steps turned
5. Degrees head rotated
6. Transitions between navigation and exploration modes
7. Collisions with wall

All will be compared to manual-control
Video!
## Results

<table>
<thead>
<tr>
<th>Subject</th>
<th>Session</th>
<th>Total time (sec)</th>
<th>Distance travelled (cm)</th>
<th>Forward steps (times)</th>
<th>Turning steps (times)</th>
<th>Explored angle (rad)</th>
<th>Transitions (times)</th>
<th>Collisions (times)</th>
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<td>507.8</td>
<td>434.4</td>
<td>134.0</td>
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<td>570.2</td>
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<td>Overall</td>
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<td>562.7 (±59.0)</td>
<td>443.6 (±20.6)</td>
<td>141.5 (±7.2)</td>
<td>42.3 (±4.5)</td>
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<td>Manual (±SD)</td>
<td>463.5 (±43.6)</td>
<td>454.5 (±32.7)</td>
<td>142.7 (±10.4)</td>
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Conclusions

Success Evaluation

1. Low-cost BCI worked well enough to complete the task.
2. Task completion wasn’t super slow.

Hybridization of simple BCI tasks is pretty good and when aggregated can solve complex tasks.

Current Low-Cost BCI Challenges

- Emotiv Epoc limited # channels, meant overlapping ERD/SSVEP signals
- Headset could move/shift
- Headset did not cover full sensorimotor cortex regions
- Limited, and lower, frequencies
Limitations, Takeaway

- Five-Subject Study
  - All male, right-handed, healthy, 19-27 yo, no prior BCI experience

- Complex task still not super realistic
  - Paper images... of fruit
  - Small maze (1.5 x 3.0 m²)
  - All 90° turns
  - p slow

- Aggregating solutions to small tasks seems to work well,
  Hybrid BCI::BCI Problem ~ Ensemble Methods::ML Problem
Thank You!
References


Product Info

https://www.emotiv.com/epoc/
https://www.youtube.com/watch?v=JvxdbpTcTnc “Fly AR.Drone 2.0 with your mind & Emotiv EPOC"