A Hierarchical Architecture for Adaptive Brain-Computer Interfacing

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Motivation:
- Non-invasive BCIs, such as electroencephalographic (EEG) signals, suffer from low-signal-to-noise ratio which limits the bandwidth of control.
- Traditional BCIs for robotic control have a trade-off between cognitive load and scalability. More robotic autonomy [1] implies coarse-grained control and less flexibility, while fine-grained control [2] provides greater flexibility but higher cognitive load.
- Hierarchical architecture for brain computer interfacing allows a user to teach the BCI new skills on-the-fly; these learned skills are later invoked directly as high-level commands, relieving the user of tedious low-level control.

Methods:
- Three main components in hierarchical BCI
  1. EEG-based BCI, e.g. steady state visual evoked potential (SSVEP).
  2. Hierarchical menu and learning system that allows the user to teach the BCI new skills.
  3. The application, e.g. a simulation of a humanoid robot, wheeled robot, or real PR2 semi-humanoid robot.

Figure 1. A Hierarchical BCI System. A. Experimental setup. B. Application. C. Menu and SSVEP stimulation. D. Frequency domain of a subject’s EEG signal.

Hierarchical Menu

Figure 2: Overview of control flow in the hierarchical menu system.

Results:
- Study1: Testing the Hierarchical Architecture.

<table>
<thead>
<tr>
<th></th>
<th>Low-level BCI</th>
<th>Hierarchical BCI</th>
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<tbody>
<tr>
<td>Num Selections</td>
<td>20 (7)</td>
<td>5 (2)</td>
</tr>
<tr>
<td>Task Time</td>
<td>220 (67)</td>
<td>112 (25)</td>
</tr>
<tr>
<td>Nav Time</td>
<td>124 (37)</td>
<td>73 (19)</td>
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</tbody>
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Mean of three trials from best subject (std)
- Num Selections: 8 (4)
- Task Time: 91 (75)
- Nav Time: 59 (59)

Figure 3 & Table 1. Example Robot Trajectories from User-Demonstrated Low-Level Control and Hierarchical Control and Performance Comparison.

Study2: Uncertainty-Guided Interaction [4].

Study3: Scaling up to Real Robot and Complex Task Learning [5].

Conclusion:
- Combining Scalability and Efficiency
- Interaction Based on Probabilistic Model
- Hierarchical Architecture, Learning with both low and high level skills
- Multi-tasking for Increasing Bandwidth
- Long-term usability

References:

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