Task Level Hierarchical System for BCI-enabled Shared Autonomy

Iretiayo Akinola, Boyuan Chen, Jonathan Koss, Aalhad Patankar, Jake Varley & Peter Allen
Columbia University
Shared Autonomy

Agent 1

Agent 2
Why BCI Interface?

- Robust Assistive Robotics Application
  - Can be used by humans with disabilities
- Complementary to other interfaces for complex tasks
  - Expand range of interface modalities
- Move BCI from the lab into real world
  - BCI Robotics Applications e.g. Home-Assistant Robot
  - Spur growth in BCI technologies
Which BCI?

Different BCI imaging modalities measure brain activity:

- electroencephalography (EEG),
- near-infrared spectroscopy (NIRS),
- magnetoencephalography (MEG),
- functional magnetic resonance imaging (fMRI),
- electrocorticography (ECoG), and
- intracortical electrode recordings
EEG-BCI Neural Patterns

SSVEP- Steady-State Visual Evoked Potentials

MI- Motor Imagery (Use Sensorimotor Rhythms)

ErrP- Error related Potentials

Affective States
SSVEP

- Visual Stimulus Driven
- Split frequency band (6-9.5Hz) into # options
- 2 Electrodes in Occipital region (O1 & O2)
- canonical correlation analysis (CCA)

Options are presented to human agent as visual stimuli
SSVEP Pros & Cons

Pros

● require no training
● analysis is fairly simple
● reliable and robust response.
● provides high temporal resolution signals for analysis

Cons

● Requires stimuli
● Discomfort over time
● Small Latencies
Robot Autonomy

- **Navigation**
  - SLAM (ROS package)

- **Vision Processing**
  - Point Cloud Segmentation
  - SSVEP Stimuli generation

- **Manipulation**
  - Shape completion
  - Grasp planning (GraspIt!)
  - Trajectory Planning (MoveIt)
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SLAM- Simultaneous Localization and Mapping

- Mapping - building of a model of the environment
- Localization - estimation of the state of the robot
  - Noisy measurement from sensors (e.g. range sensors, odometry)

Position state estimation (ACT and SEE cycle)

- SEE: Laser scanner
  - A range of 25m, 220° field of view, 15Hz update rate
  - Angular resolution of 1/3°
- ACT: Mobile Base
  - 2 active wheels, 2 free turning wheels
  - Wheel Encoders (resolution not in manual)
SLAM

Position state estimation (ACT and SEE cycle)

1. Sense. Update the estimated state from registering landmarks. (SEE)
2. Build Map- Add new landmarks to the current state.
3. Move to a new location (ACT)
4. Update state estimate using the odometry data
Slam Output
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Point Cloud Segmentation

Euclidean Cluster Extraction

- create a Kd-tree representation for the input point cloud dataset \( P \);
- set up an empty list of clusters \( C \), and a queue of the points that need to be checked \( Q \);
- for every point \( p_i \) in \( P \)
  - add \( p_i \) to the current queue \( Q \);
  - for every point \( p_i \) in \( Q \)
    - search for the set \( P_i^k \) of point neighbors of \( p_i \) in a sphere with radius \( r < d_{th} \);
    - for every neighbor \( p_i^k \) in \( P_i^k \), check if the point has already been processed, and if not add it to \( Q \);
    - when the list of all points in \( Q \) has been processed, add \( Q \) to the list of clusters \( C \), and reset \( Q \) to an empty list.

the algorithm terminates when all points \( p_i \) in \( P \) have been processed and are now part of the list of point clusters \( C \).
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Hierarchical System

- Home-Assistance Robot
  - Assign Task
    - Clear Table
      - Which table?
    - Fetch a Drink
      - From where?
    - Get a Book
      - Which book?
    - Other task ...
  ...
  ...
  ...
  ...
Hierarchical System - An Instantiation

(a) Start → Select Table → Move to Table → Run Vision → Select Objects
   Repeat until cleared → Place Object
   Select Place Location → Grab Choice Object

(b) Options → Stimuli Generation → BCI Signal Classification → Return Choice Index
Table-Clean Up Experiment

Where do I go?
Go to the table.

What should I grab?
Pick up the drill.

Where do I take it?
Bring it to me...

fetch Robotics

[Image of robot and cleaning supplies]
Video

press for video
Evaluation Criteria

● BCI Success Rate (User Input Detection)

● Mean Time Distribution Between Stages

● Mean Time to Completion

  ○ ranged from 439s to 543s (mean = 481.3s)
Results

**TABLE II: User study results for table cleanup task.**

<table>
<thead>
<tr>
<th>Subject</th>
<th># of Trials</th>
<th>SSVEP Classification Success (# successful queries / # queries)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>15/15 (100%)</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>11/12 (91.7%)</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>11/12 (91.7%)</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>14/14 (100%)</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>15/15 (100%)</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>14/15 (93.3%)</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>15/15 (100%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total: 95 / 98 (96.9%)</strong></td>
</tr>
</tbody>
</table>
Mean Time Distribution Between Stages

Duration of Human Input - black dotted line
SSVEP: Performance Considerations

- Stimuli duration
- Number of options

![Graph showing mean classification accuracy vs. duration of signal used for classification (s)]
Summary

Hierarchical system for shared control of a humanoid robot.

- **Shared Autonomy**
  - Leverages the strengths of both humans and robots.
  - Reduces BCI Fatigue
- **Hierarchical and configurable**
- **Intuitive screen-based visualization of the task**
  - Enhances operator understanding and interaction.
  - Web-based System (RoboWebTools); platform-agnostic
- **Robust Assistive Robotics Application**
  - Reliable BCI with SSVEP
- **Benchmark Experimental Setup for Evaluation of BCI Systems**
Current/Next Steps

Benchmark Evaluation of BCI-Robotic Systems

- Simulated Robotic environment
- Compare performance of different BCI Modalities
- SSVEP versus Eye-Tracking
- Hybridize BCI Modalities (SSVEP + fNIRS)

BCI Robot Learning

- Interactive Robot Learning using BCI
Questions? ..... Happy Thanksgiving!