Task Level Hierarchical System for BCI-enabled Shared Autonomy

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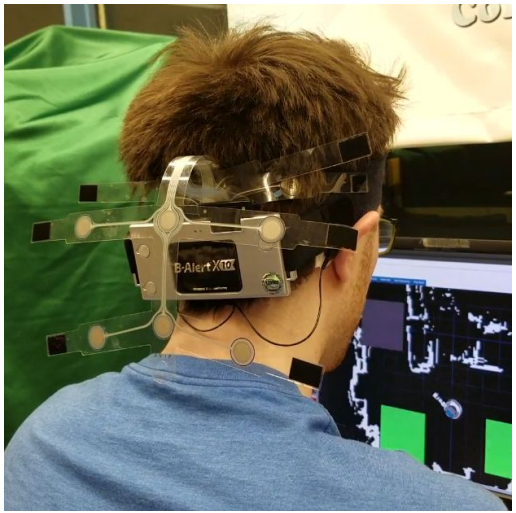

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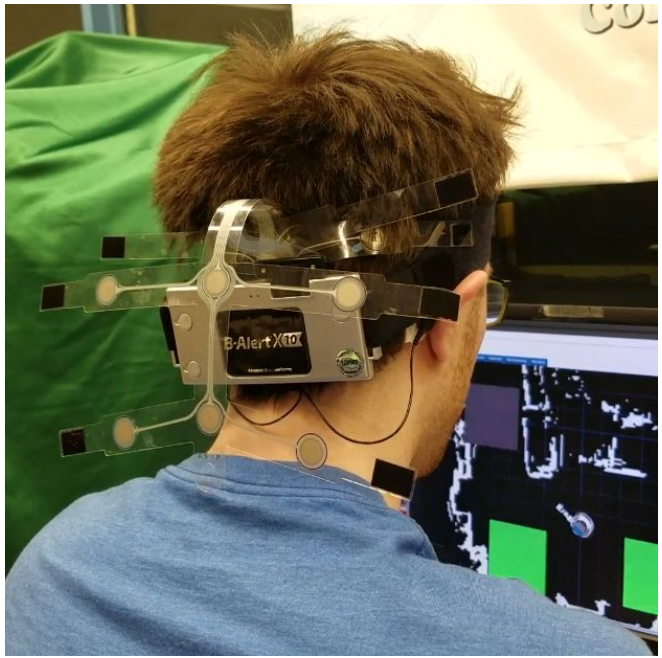
Shared Autonomy

Agent 1



Agent 2

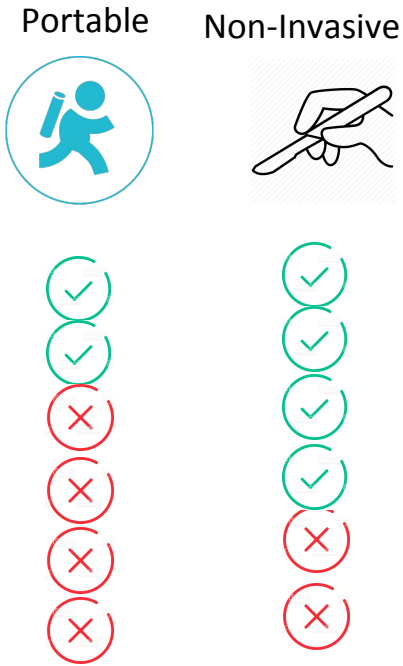
Why BCI Interface?

- Robust Assistive Robotics Application
  - Can be used 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



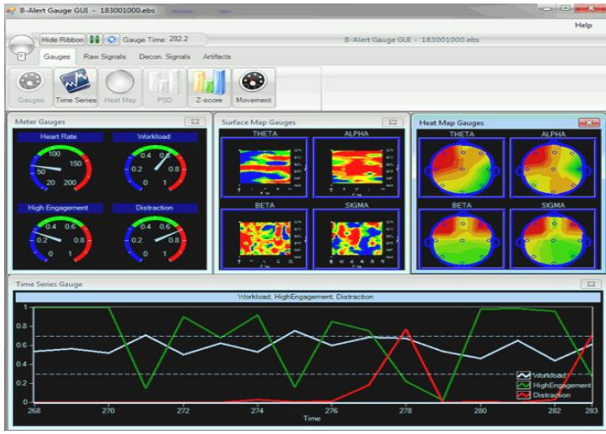
EEG-BCI Neural Patterns

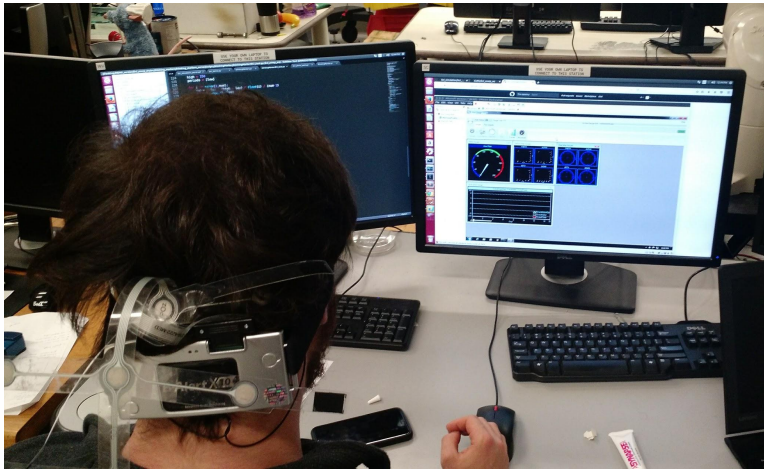
SSVEP- Steady-State Visual Evoked Potentials

MI- Motor Imagery (Use Sensorimotor Rhythms)

ErrP- Error related Potentials

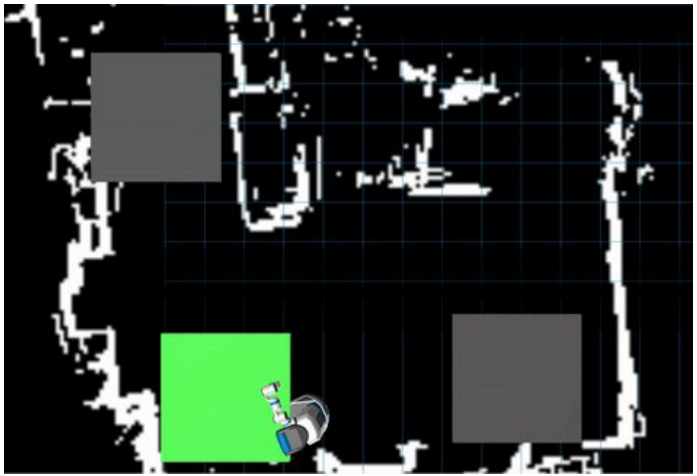
Affective States





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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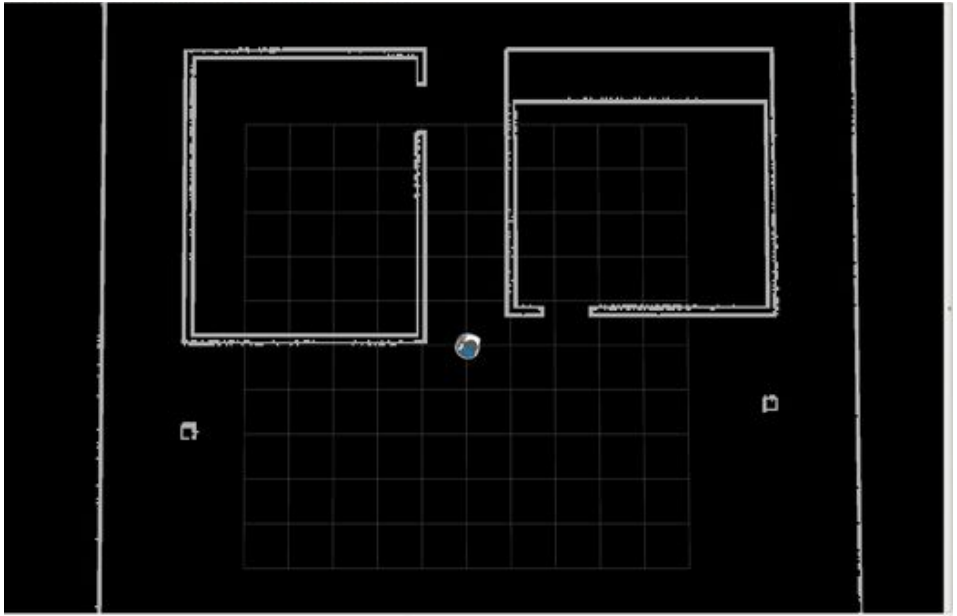


SLAM- Simultaneous Localization and Mapping

- 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)

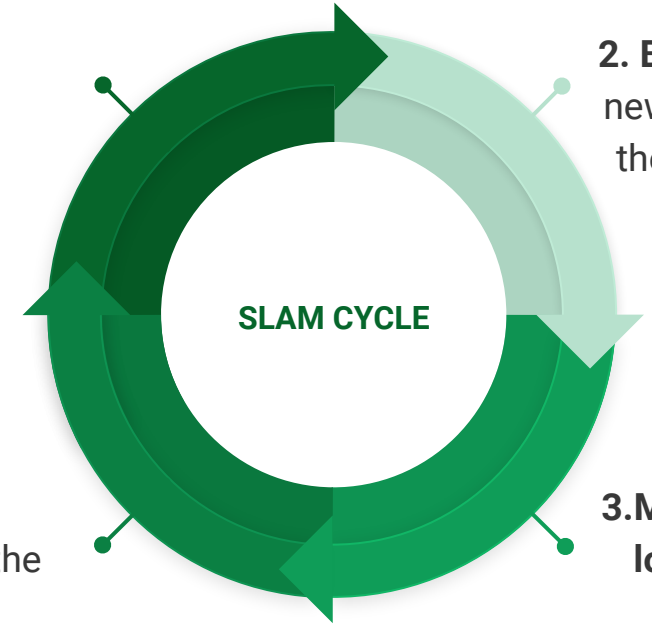
Position state estimation (ACT and SEE cycle)

- 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)

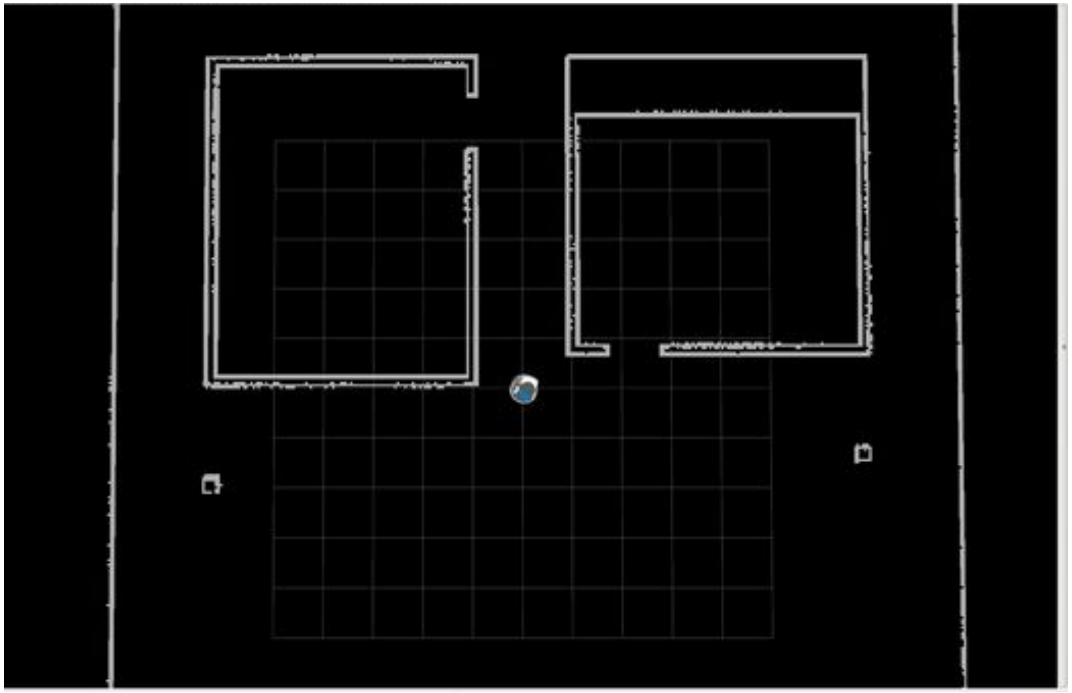


2. Build Map- Add new landmarks to the current state.

3.Move to a new location (ACT)

4. Update state estimate using the odometry data

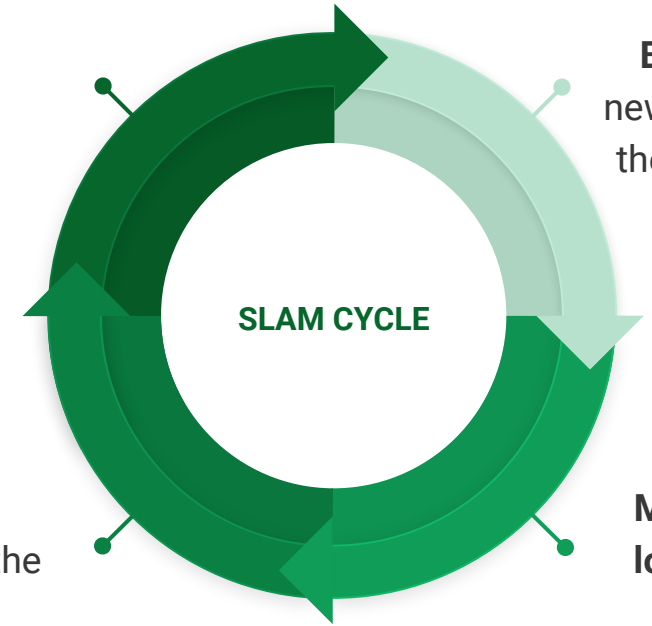
Demo: SLAM in Action



SLAM

The robot estimates the belief state about its position through an ACT and SEE cycle

Sense. Update the estimated state from registering landmarks. (SEE)



Build Map- Add new landmarks to the current state.

Update state estimate using the odometry data

Move to a new location (ACT)

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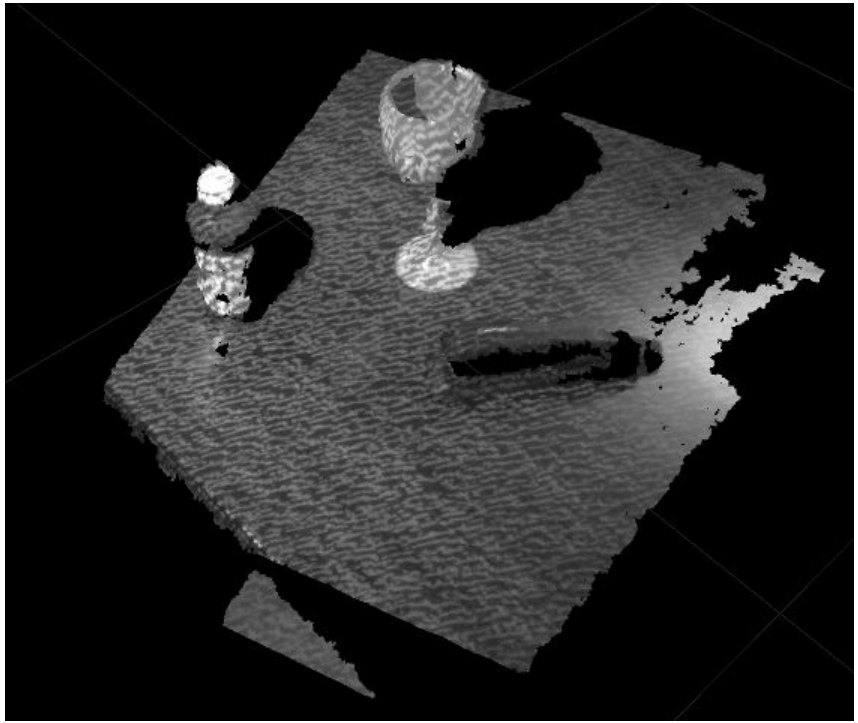
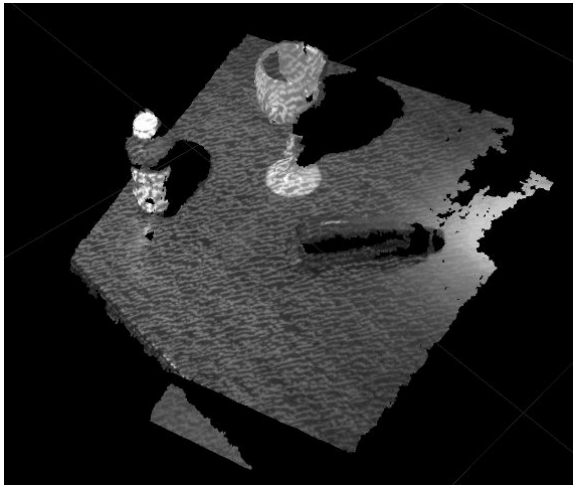


Point Cloud Segmentation

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



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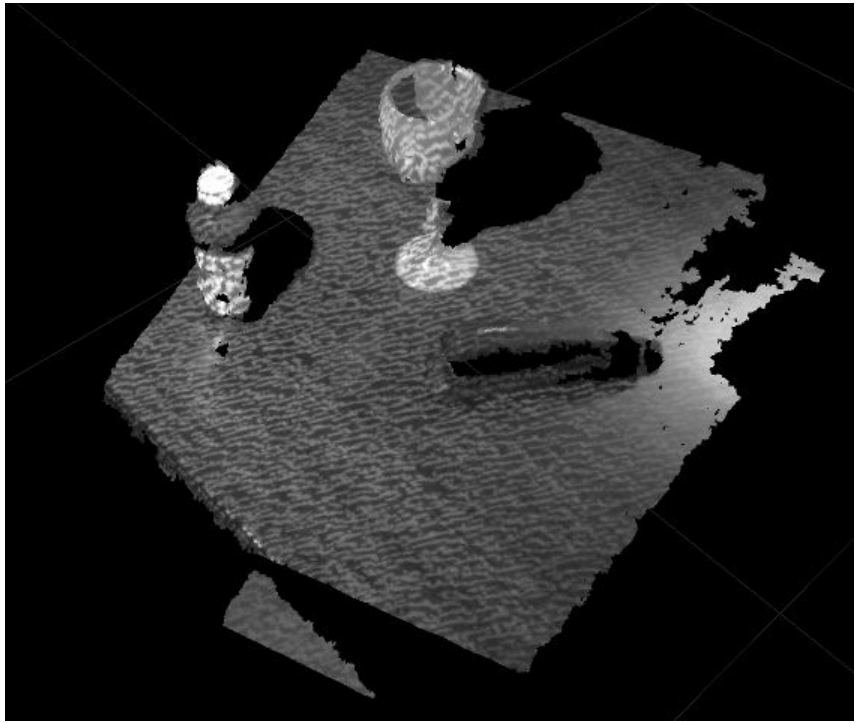

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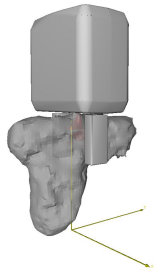
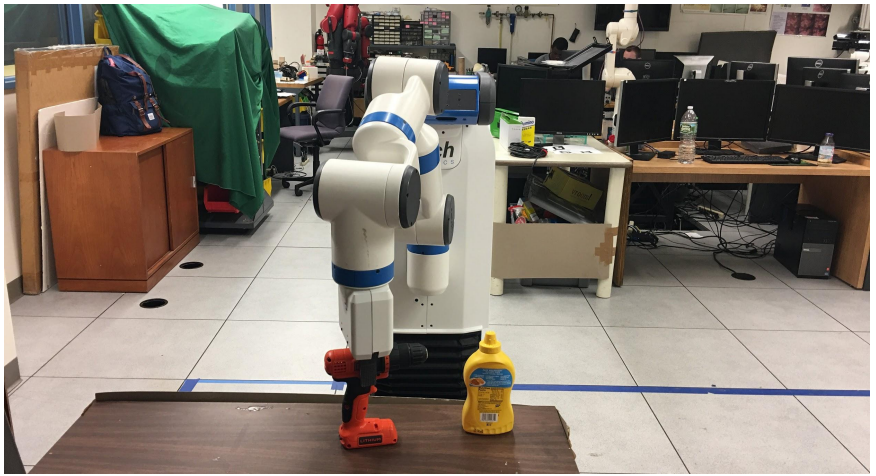
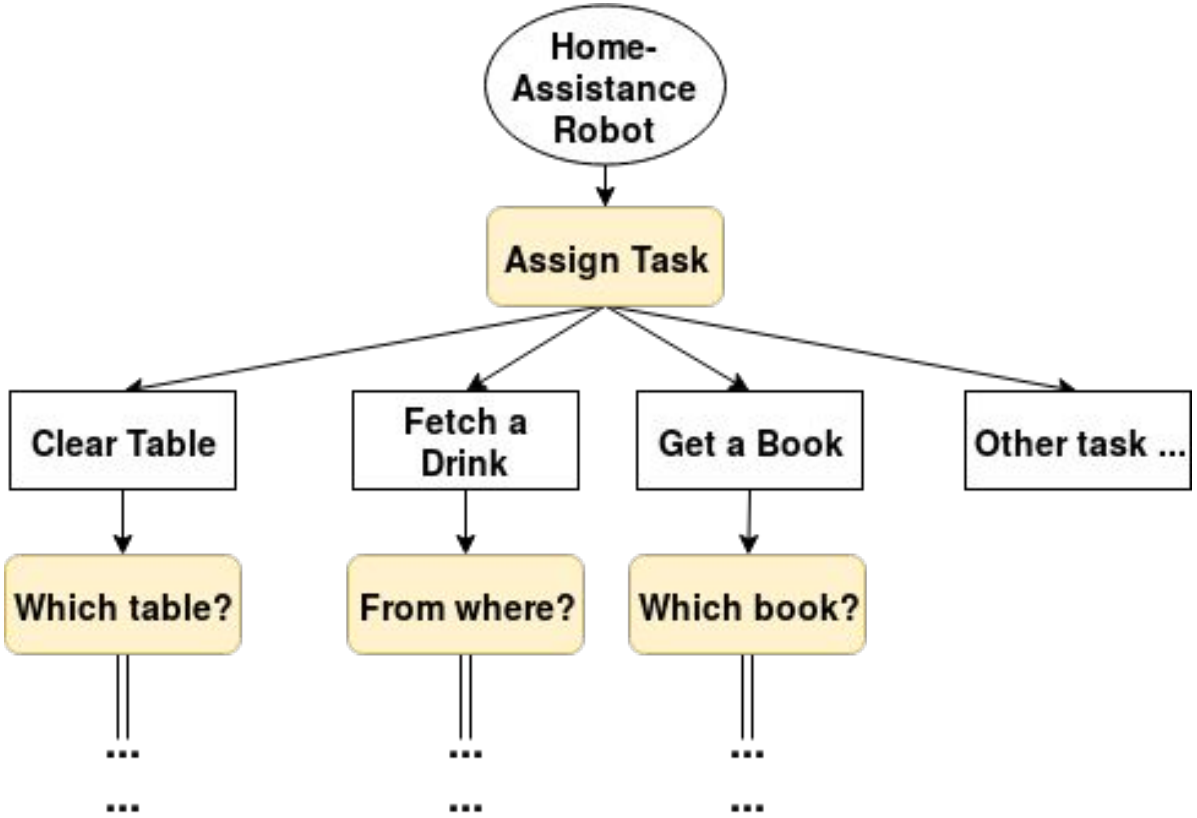




Hierarchical System



Hierarchical System- An Instantiation

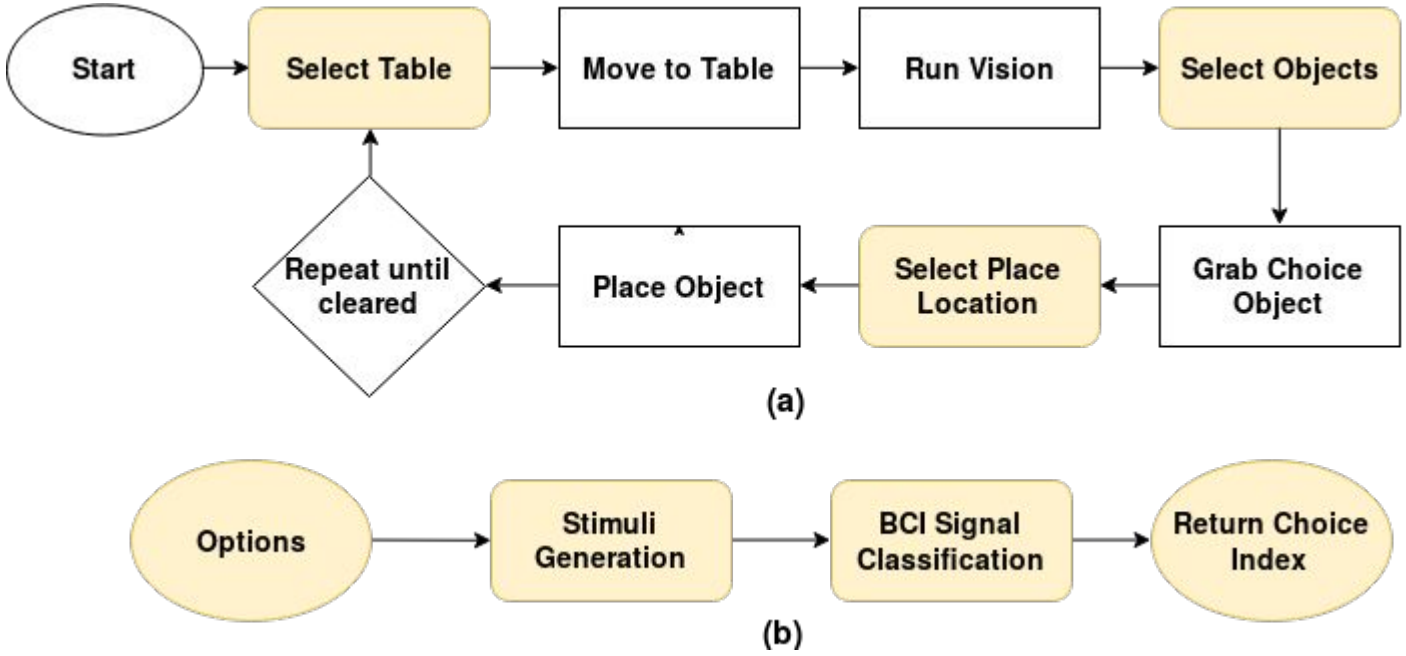
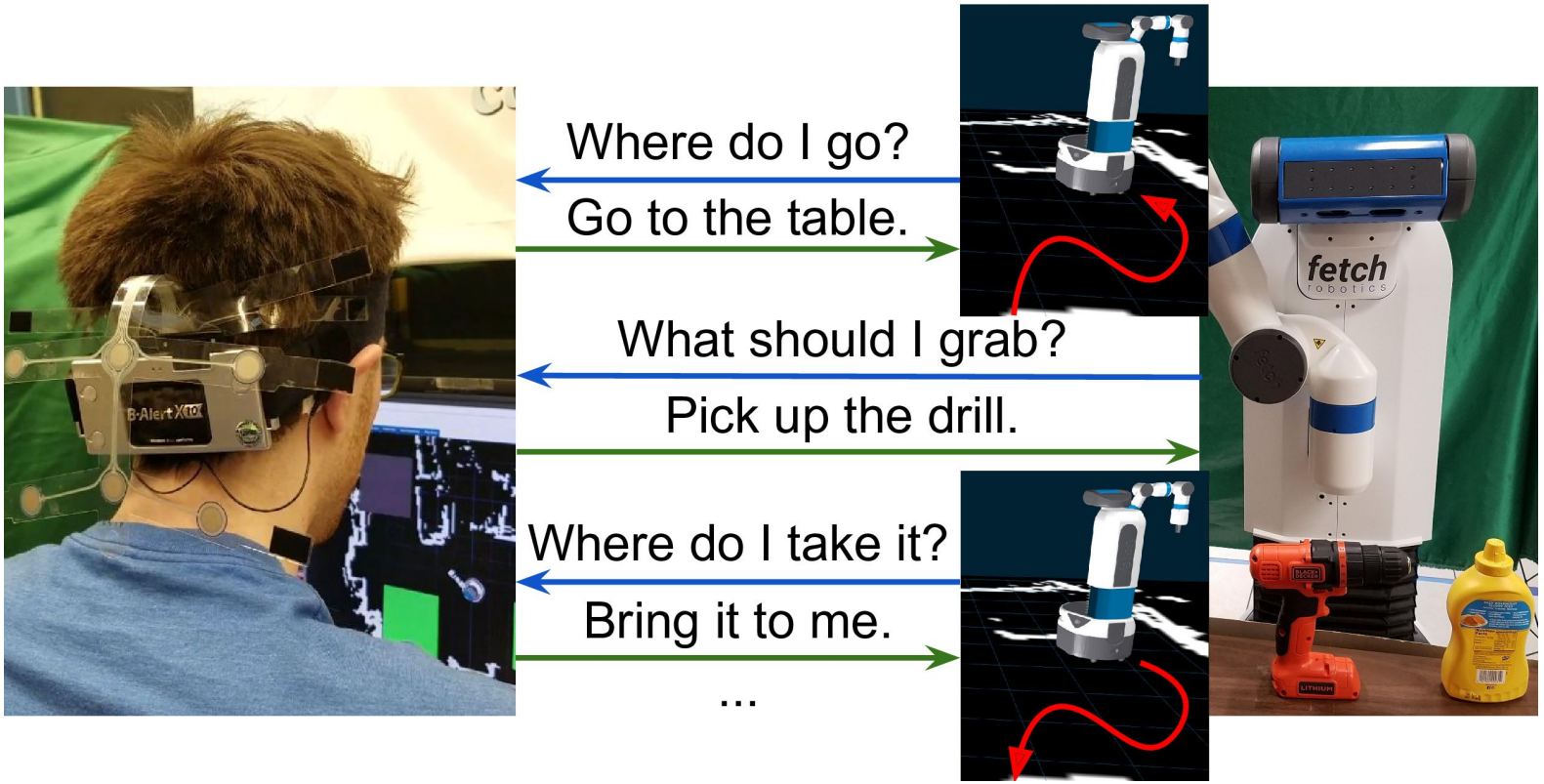


Table-Clean Up Experiment



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)

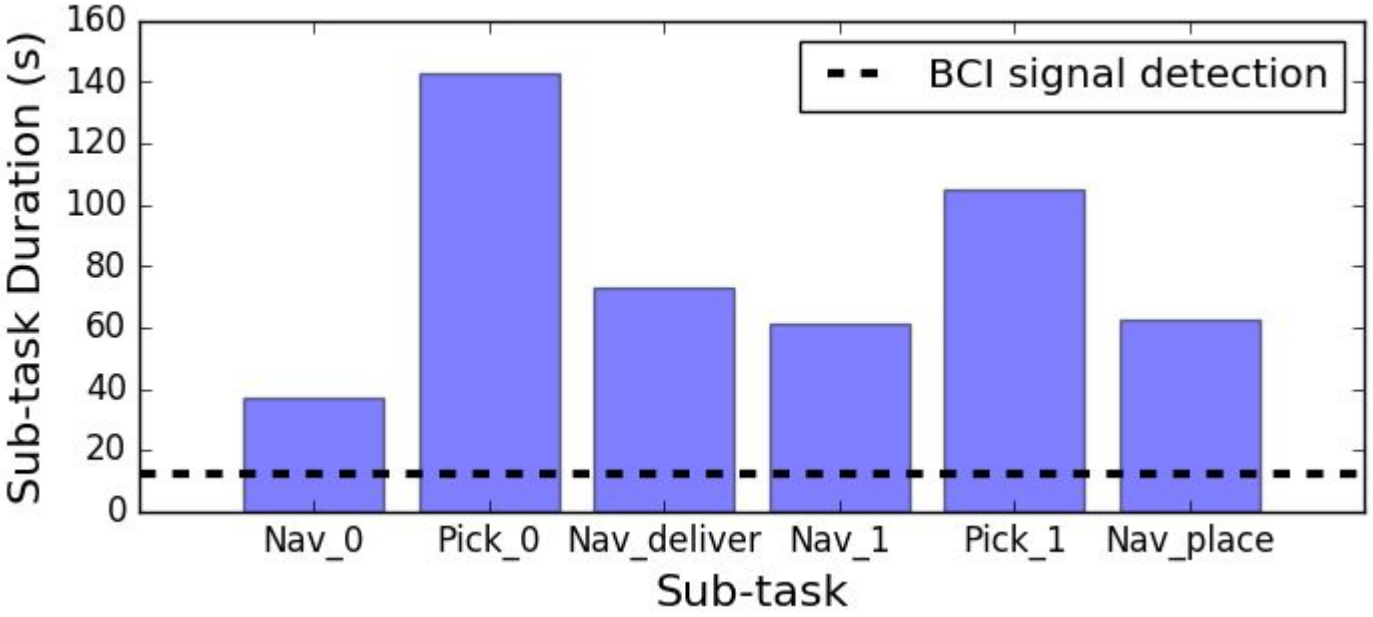
Results

TABLE II: User study results for table cleanup task.

Subject	# of Trials	SSVEP Classification Success (# successful queries / # queries)
1	3	15/15 (100%)
2	3	11/12 (91.7%)
3	3	11/12 (91.7%)
4	3	14/14 (100%)
5	3	15/15 (100%)
6	3	14/15 (93.3%)
7	3	15/15 (100%)
		Total: 95 / 98 (96.9%)

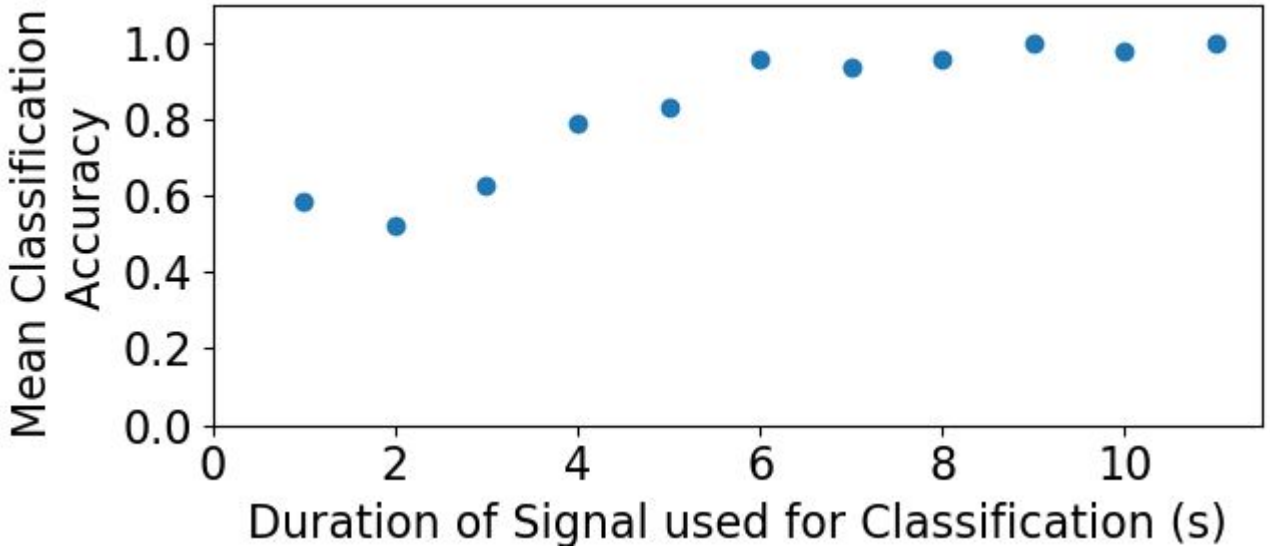
Mean Time Distribution Between Stages

Duration of Human Input- black dotted line



SSVEP: Performance Considerations

- Stimuli duration
- Number of options



Summary

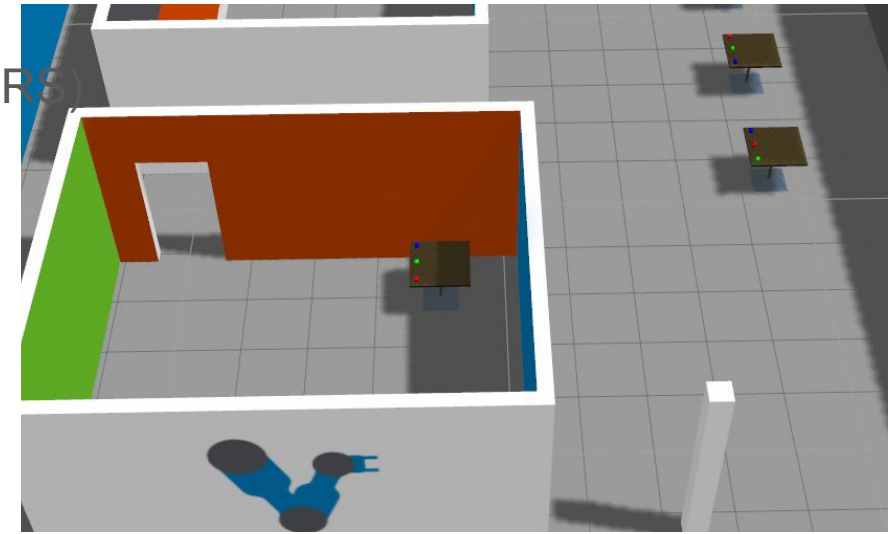
Hierarchical system for shared control of a humanoid robot.

- 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?