What You Think is What You Get: Brain-Controlled Interfacing for the PR2

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I. Introduction

Directing robots to perform remote tasks with human supervision has been a subject of considerable interest in the robotics community [1], [2], [3]. Humanoid robots in particular are often considered proxies or assistants to humans, performing tasks in real-world environments designed for humans.

Recent advances in neuroscience and humanoid robotics have allowed initial demonstrations of brain-computer interfaces (BCIs) for controlling humanoid robots [4], [5], [6]. This is of particular interest since it could allow a severely paralyzed patient to use a robot as a proxy to perform a task. With such a system, a patient would be able to issue commands to the robot without the need of physical movement.

This proposal is challenging due to the low throughput of the BCI and the high degrees-of-freedom of the robot. The BCI's low signal-to-noise ratio means less useful information may be acquired during any given time window. At the same time, the high degrees-of-freedom of the robot means a larger amount of information is necessary for full control during any given time window. A BCI/robot system must therefore provide a high-level interface which summarizes over the information necessary for full control of the robot (e.g. presenting an interface for a grasping pipeline where the BCI user only selects an object to grasp). At the same time, it must balance this high-level summary with the flexibility to achieve the tasks desired by the BCI user.

In this demonstration we present a BCI system for directing a PR2 robot's actions. The interface has been adapted for two example scenarios that are representative of possible interaction scenarios desired by a user. In the first demonstration, the interface controls a grasping interaction with objects detected in a room. This task illustrates the sort of functionality a BCI could provide in order to aid in patient autonomy. The second demonstration provides a pointing interface for the user to interact with a remote player in gameplay. This task shows how a BCI and robot proxy could aid in human-to-human social interactions. These are representative of two broad classes of robotic teleoperation applications.

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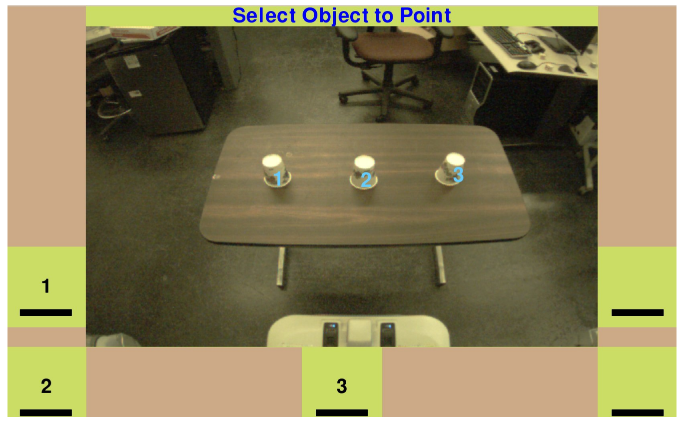

Fig. 1. Example screen from graphical interface. The user monitors the robot's state through a video feed on this screen. This screen also displays potential commands. In this case, it displays a list of objects to which the robot can point.

In the first scenario, we allow the user to rotate the head to look for objects, then select an object for grasping. The PR2 uses point cloud data to identify objects and presents them to the BCI user as numbered objects via a graphical interface. Once the user selects an object, PR2 will then use a grasping routine to attempt to grasp the object.

Second, we have the user play a "shell" game in interaction with a dealer. The dealer hides an object under one of three "shells" (cups), then mixes them around. The BCI user watches the mixing process and guesses under which shell the object can be found. Once the dealer signals they are done mixing, the BCI user controls the PR2 to point at a particular shell. (See Fig. 1)

II. Architecture

In both demonstrations we use a BCI based on the Steady State Visually-Evoked Potentials (SSVEP) paradigm. This type of BCI operates by exposing the user to oscillating visual stimuli. Electrical activity corresponding to the frequency of this oscillation (and its multiples) can be measured from the occiptial lobe of the brain located at the back of the skull. The user issues a command by choosing a stimulus (and therefore a frequency) to pay attention to. The BCI measures the corresponding EEG activity and attempts to infer from it the command the user has chosen for execution. [7]

The menu displays a live video feed from one of PR2's wide stereo cameras. This allows the user to monitor PR2's current situation. It also lays out a context-sensitive series of commands for the user. Each command corresponds to one stimulus frequency. For instance, if the user concentrates on the stimulus located next to the "2" command on this menu screen (See Fig. 1), the BCI system will consider this a command to point to object 2, as labeled in the video.

After each action command is made, a confirmation menu is displayed before the selected action is executed. Due to noise inherent in many BCIs, the system may misconstrue the user's intentions. The confirmation screens help ensure that the interface properly interprets the user's intentions.

For the second demonstration, PR2 points to objects using the move arm package, which allows collision-free arm motion. We use the Microsoft Kinect to obtain point clouds of the cups on the table.

III. Demonstrations

A. Demonstration 1 - Object Grasping

In the first demonstration, the user is attempting to pick up an object. The user swivels the PR2's head around looking for an object they are interested in grasping. In this case, graspable objects sit on a table in front of PR2. Once the head moves to the new position, the BCI system calls the built-in ROS tabletop object detection and collision map processing. We use these to find any objects on the table and within the user's view. As PR2 discovers objects within view, they are presented to the user. The action choice menu labels the detected objects numerically. Then the user selects an object for the PR2 to grasp. At this point the menu system displays a confirmation screen. If the user selects "Yes, a grasping action executes without futher control from the user. For grasping automation, we use the built-in ROS object manipulator package. Upon a successful grasp, the object is brought close to the camera for user inspection. (See Fig. 2 for experiment flow)

B. Demonstration 2 - Interaction in Gameplay

In the second task, the user plays a "shell game", via the PR2, with a human dealer. The dealer places an object under one of three "shells" (cups), and then mixes them around. The user monitors the mixing process through video feed and attempts to identify the cup under which the object can be found. Once the mixing is complete, the dealer sends a signal to start the user's turn. When this signal is received, the point cloud data from the Kinect is used to detect the cup cloud centroid locations, which are returned to the menu system and once again displayed as numbered selection choices. The user can then select the cup under which they think the object is located and the PR2 will point to that cup using the arm closest to the object.

IV. Future Projects

Our ongoing research efforts include:

1) Incorporating more pre-programmed robotic skills such as auto-navigation to further reduce user training time and allow the user to focus on learning higher-level command sequences;
2) Expanding our previous work on hierarchical BCIs [6] through the use of additional machine learning techniques. These will automatically extract common command or state sequences and present them to the user as high-level skills without the need for the user to provide explicit training;
3) Augmenting brain signals with other signals such as eye movement, voice, and muscle-based commands to explore the full-range of human biological control of humanoid robots.

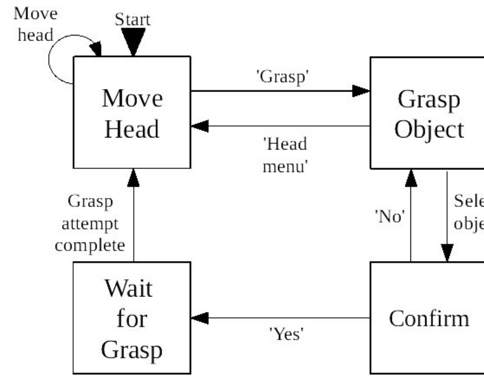

Fig. 2. Overview of control flow in the menu system for demonstration 1. Black triangle indicates starting state.

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